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JAMES DWIGHT DANA AND HIS WORK AS A GEOLOGIST.

JAMES DWIGHT DANA, who for a generation has been our foremost geologist, on the fourteenth day of last April, died at the ripe age of eighty-two years. It is difficult to appreciate how much American geologists owe to the indefatigable industry of this one man; though he has laid down his pen, the results of his labors remain with us, and are wrought into the very foundation structure of American geology. The main events of his busy life have been narrated in many places; one of the most vivid sketches is the one published in the *American Journal of Science*, written by his son. To this we would refer for a clear view of the many-sided life as a whole.

There were certain conditions of birth and early education — certain traits of character — and events in his early life, which in some measure specially prepared him for the career which he so successfully carried out. A few of these may be here recounted as an introduction to this brief sketch of his work as a geologist.

Dana was the son of an active, successful business man; and the qualities of business common sense, industry and economy thus acquired, although he chose to apply them in other than commercial pursuits, were elements of inheritance which contributed greatly to the quality of his greatness and success.

In his boyhood he had the stimulation of a great teacher,

whose enthusiasm for natural history tempered by a thorough English culture and education, stirred in him the appetite for investigation and the reverence for the truth, which never left him, but grew with his growth and became the dominating qualities of his character.

Having determined to devote his life to the study and interpretation of nature he chose the most direct ways of fitting himself for the work. He felt the importance of a liberal college education, and entered the Class of 1833 in Yale college, where Silliman was making himself and the college famous for the teaching and encouragement of science. With Silliman he became a devoted pupil of mineralogy, chemistry and geology, but particularly of the first. Silliman's public lecturing began while Dana was in college, and the course of lectures in Hartford in 1834, and the Lowell lectures in Boston in 1835, were the beginning of awakening of the public interest in science throughout America.

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Comparing him with others, the influence of this liberal education is seen throughout his writings, in the remarkably philosophical grasp, in the deep insight with which every subject of his investigation was handled, and in the breadth of his interests and his thorough appreciation of the true proportions and relations of things to each other.

He also had the extraordinary advantages of wide travel, which particularly fitted him to be an interpreter of the grander problems of geology, to which in the latter half of his life he gave chief attention. Immediately after graduation he took a cruise on the U. S. Frigates "Delaware" and "United States," across the Atlantic and about the Mediterranean, in the capacity of teacher of mathematics to the midshipmen, but learning and observing meanwhile, studying mineralogy and crystallography inside his cabin, and seeing whatever he could see on sea and land outside. His first scientific paper was written from the U. S. Frigate "United States," in 1834, "On the condition of Vesuvius in July 1834."[1]

[1] See American Journ. Sci. (1) Vol. XXVII., pp. 281–288.

The other and chief voyage was with the United States exploring expedition under Commodore Wilkes, which sailed in August 1838 and reached New York on the return in June 1842. The route took him through the Southern Atlantic, the Straits of Magellan, up the western coast of South America, among the islands of the Pacific, to the western coast of North America, where he was shipwrecked and went overland from the mouth of the Columbia River through Oregon, across the flank of Mt. Shasta and through north California to San Francisco, thence across the Pacific again to the Sandwich Islands, Singapore and around the Cape of Good Hope into the Southern Pacific and thence home to New York.

In this long cruise he acted in the capacity of geologist and mineralogist, but by the failure of others to fill their places, he ultimately became the observer and reporter on all the natural history. The official reports he wrote were three: the first, "On Zoöphytes," 741 pages with a folio atlas of 61 plates, was published in 1846; the second, "On Geology," 756 pages, with a folio atlas of 21 plates, was issued in 1849. The third was "On the Crustacea," in two parts, with a total of 1620 pages and 96 folio plates, and was issued in 1854. A large number of lesser papers and treatises were founded upon facts accumulated during this voyage, or upon investigations carried on in elaborating those observations.

Three lines of investigations, which continued to occupy his attention more or less to the end of his life, were the direct outcome of the experiences of this voyage; these were about 1) Corals and Coral Islands, 2) Volcanoes and the associated problems of mountain making and continental development, and 3) Cephalization; the last topic being incident to the studies made in preparation of the report "On Crustacea." In each of these problems he took keen interest and contributed greatly to their elucidation. His interest in volcanoes led him to make a journey to the Sandwich Islands in the latter part of his life (1887) to see for himself the changes that had taken place, and to compare Kilauea and other volcanoes of Hawaii as they had become, with their condition as observed by him in 1840. As a result of these new

studies he wrote "Characteristics of Volcanoes, with contributions of facts and principles from the Hawaiian Islands," 400 pages, in 1890. Much might be said in elaboration of this subject, — the influence of the experiences of 1838–42 in shaping his future investigations and contributions to science — and some of the developments of his geological theories and works will be briefly traced beyond; but space will not here admit the discussion of the equally interesting contributions Dana made to the subject of organic evolution and the correlations between the conditions of life, geological time, and the structure and form of organisms. His studies in the several fields of organisms, minerals and geology made in the earlier, most active period of his life (if there was any time in his life when his activity was abated except by sickness) were an important factor in enabling him to understand nature intimately in her more hidden workings, which by most observers is seen from only one side and therefore but partially comprehended. After returning from the exploring expedition, he spent two years at Washington working on the reports, then he went to New Haven where he resided throughout the remainder of his life.

In the interval between the first two ocean voyages, he was Professor Silliman's Assistant in Yale college, and then produced his first important work, *A System of Mineralogy: including an extended treatise of crystallography with an appendix containing the application of mathematics to crystallographic investigation, and a mineralogical bibliography*. The first edition was of 594 pages and was published in 1837. The title though long gives a concise description of the scope of this book which at once took a first place as a treatise on mineralogy in the English language, and in its successive editions it has not lost its place up to the present day.

That geology was his favorite study is shown by the number of titles in the bibliography. Dividing the list by decades, beginning with 1835, for the first three decades the number of titles is almost equally distributed in the three groups: Geology 37, Mineralogy 34, Zoölogy 38. After 1865, however, but seven

papers are strictly mineralogical, and but five were devoted to zoölogy, while of geological papers and books, there are nineteen between '65 and '75, thirty-three between '75–'85, and in the last decade of his life thirty-one, making a total of 120 titles in the geological list, an average of two per year for the whole period of sixty years of his literary activity.

Mineralogy, which first attracted his interest, was early perfected into a system, and after the time of his taking the professorship in Yale college he wrote few special papers on mineralogy, and thereafter turned his attention more and more to geological studies. The 4th edition of the *System of Mineralogy* appeared in 1854 with the fully perfected chemical classification. The 5th edition, which included the complete systematic description of known mineral species, was prepared with the assistance of Professor G. J. Brush, and in the preparation of the 6th edition by his son Edward S. Dana, he was unable to take an active part.

His chief zoölogical works were the reports "On Zoöphytes" and "On Crustacea" of the Wilke's exploring expedition; the former was published in 1846, the latter in 1854. A considerable number of papers were written "On Cephalization," in which he was deeply interested up to about 1866, after that date he produced scarcely anything of purely zoölogical nature.

Geology is a much more complex and miscellaneous science than either mineralogy or zoölogy, and therefore it is difficult to so arrange the facts as to exhibit their relation to any single common principle. But we believe Dana's *Manual* has come nearer to the setting forth of such an ideal system of geology than has been elsewhere attained. The central ideas in this system are: (*a*) the earth a cooling globe,— (*b*) contracting as it cools,— (*c*) differences of depression and elevation of the surface the direct result of the unequal contracting,— (*d*) oceans and continents permanent,— (*e*) trends of shores, of islands and mountains, according to system, and expressive of lines of weakness, and of chief foldings and fractures, (*f*) epeirogenic and orogenic phenomena the direct results of the contracting,— (*g*) climates and currents of the ocean also the effects of changes

in elevation of the continents, — (*h*) the separation of the history of the earth into ages by the revolutions at the climaxes in the contraction, when strain and tension came to exceed strength and resistance, and resulted in folding and faulting and local disturbances, and were marked by the greater or less extermination of life, followed by repeopling by, and the modification of the successors, — (*i*) the surface shaping of the continents by ice and water action also influenced by oscillation of level of the continents; and all of these various factors taking a part in producing the present complex condition of the earth's surface.

The earth as a whole was the unit which was before his mind as he constructed this system of geology. As he traced its history he saw in the successive events of geology the marks of the gradual development of a vaporous, then incandescent, and finally hardened, contracting, cooling globe. Others had spoken of geology as a history; but he appears to have been the first to write a manual of geology in English based on this idea. "In history," he commented, "the phases of every age are deeply rooted in the preceding, and intimately dependent on the whole past. There is a literal unfolding of events as time moves on, and this is eminently true of geology." Hence he began his geology with the beginnings, and followed the course of the history of the earth onward.

Again, to Dana the means of measuring the sequence of events was the succession of fossils. "Geology is not simply the science of rocks, for rocks are but incidents in the earth's history, and may or may not have been the same in distant places. It has its more exalted end, — even the study of the progress of life from its earliest dawn to the appearance of man; and instead of saying that fossils are of use to determine rocks, we should rather say that the rocks are of use for the display of the succession of fossils. Both statements are correct; but the latter is the fundamental truth in the science." It was this idea which dominated in his classification of geological formations.

American geologists are all aware that it is from the use of Dana's system that the habit of speaking of geological Periods

and Epochs has been acquired. Other manuals speak of formations, systems and étages, of series and groups; rocks being classified as if they were distinguished by some qualities of their own. It is from Dana that we have learned to classify geological formations in relation to the stages of progress in the building of the continents and its local structural features, and to regard rocks as not simply aggregates of mineral matter, but as geological formations bearing a definite relationship to the progress in the history of the earth, and hence as belonging to, and to be defined as of a particular period or epoch. In the first edition of his *Manual* in 1862 the author wrote:

"It has been the author's aim to present for study, not a series of rocks with their dead fossils, but the successive phases in the history of the earth,—its continents, seas, climates, life and the various operations of progress."[1]

The grand outlines of Dana's system of the earth's development are given in a few sentences in his article "On the Plan of Development in the Geological History of North America," first published in the *American Journal of Science* in 1856.[2]

"What then is the principle," he wrote, "of development through which these grand results in the earth's structure and features have been brought about? We detect a plan of progress in the developing germ; we trace out the spot which is first defined, and thence follow the evolution in different lines to the completed result: may we similarly search out the philosophy of the earth's progress? The organizing agencies in the sphere are, 1) Chemical combination and crystallization. 2) Heat, in vaporization, fusion and expansion, with the correlate force of contraction which has been in increasing action from the time the globe began to be a cooling globe. 3) The external physical agencies, preëminently water and the atmosphere, chiseling and

[1] Manual of Geology: treating of the principles of the science with special reference to American Geological History, for the use of colleges, academies and schools of science, by JAMES D. DANA, pp. xvi.+798, illustrated by a chart of the world, and over one thousand figures, mostly from American sources: Philadelphia and London, 1863.

[2] Am. Journ. Sci. II., Vol. XXII., p. 339.

moulding the surface. 4) The superadded agency of life. Of these causes, the first is the molecular power by which the material of the crust has been prepared. The third and fourth have only worked over the exposed surface. But the second while molecular in origin, is mechanical in action, and in the way of contraction, especially, it has engaged the universal sphere, causing a shrinkage of its vast sides, a heaving and sinking in world-wide movements. Its action, therefore, has been coextensive with the earth's surface through the earth's history" (*loc. cit.* p. 340). On a later page a footnote again refers to this same dominant idea: "I have alluded on a former page to an analogy between the progress of the earth and that of a germ. In this there is nothing fanciful; for there is a general law, as is now known, at the basis of all development which is strikingly exhibited even in the earth's physical progress. The law, as it has been recognized, is simply this:–Unity evolving multiplicity of parts through successive individualizations proceeding from the more fundamental onward" (p. 346).

Notwithstanding all the additions of details and statistics in illustration and elaboration of this idea, we see, up to the last, this is the dominating principle about which his system of geology was built; and the American continent, as its geological features were gradually opened to light, was recognized as the most typical illustration of this system to be found upon the globe. In the last edition of the *Manual* we find these words: "North American geology is still its chief subject. . . . The idea long before recognized [*i. e.*, before 1855] that all observations on the rocks, however local, bore directly on the stages in the growth of the continent, derives universal importance from the recognition of North America as the world's type-continent—the only continent that gives, in a full and simple way, the fundamental principles of continental development."

He was not, however, carried away by theories, his scientific research was always deep, thorough and exact. As he was preparing the report on the geology of the exploring expedition he was not satisfied with simply describing what he saw. He

not only made a thorough study of the volcanoes in the islands of the Pacific and on the borders of the South American continent, and Vesuvius and Ætna in Italy (his first scientific paper as before noticed was a letter written from U. S. frigate "United States" in 1834 "On the condition of Vesuvius in July 1834"), but in his investigations of the many questions raised by these observations he also studied the surface of the moon,—and comparison of the already cooled moon and its extinct craters with the present condition of the earth suggested the chief phenomena about which was later elaborated his theory of the earth's development as a cooling, and necessarily contracting globe.

This paper, read before the Association of American Geologists and Scientists in September 1846, "On the Volcanoes of the Moon," suggested the following: "Thoughts bearing on our own planet." 1. If the earth was once a melted globe, it must have passed through the same phases as the moon, with this very important difference, that the whole surface during its progress was subject to the denuding action of waters and from the first had valleys and sedimentary rocks in progress. 2. Certain conclusions regarding the "origin of the mineral constitution of igneous rocks," including the idea that differences in fusibility will determine the mineral combinations, and that "the same igneous rocks may occur of all ages, etc." 3. As to origin of continents "the areas of the surface constituting the continents were first free from eruptive fires. These portions cooled first, and consequently the contraction in progress affected most the other parts. The great depressions occupied by the oceans thus began; and for a long period afterward, continued deepening by slow, though it may have been unequal progress." He cites the evidence of elevations all along the geological history, the presence of marine fossils in elevated upturned strata and the depression of the oceans in the coral islands, quoting the observations of Mr. Darwin, and referring to his own, to be reported on later, in confirmation of these views. The outline of the system is tersely expressed in the closing sentence of this article:

"The principles explained place the general theory of change of

level by contraction upon something better than a hypothetical basis, and are believed to explain the actual causes by which the changes have been produced. They correspond moreover with the view that ruptures, elevations, foldings and contortions of strata have been produced in the course of contraction. The greater subsidence of the oceanic parts would necessarily occasion that lateral pressure required for the rise and various foldings of the Alleghenies and like regions."[1]

The theory was further elaborated in the following year in three papers which appeared in the *American Journal of Science* "On the origin of Continents;"[2] "Geological results of the Earth's Contraction in consequence of cooling,"[3] and "Origin of the Grand Outline features of the Earth,"[4] and was finally put into systematic form in his *Manual of Geology*.

The general contraction theory was not original with Dana, as he acknowledged in these papers. He found it advocated by Leibnitz in 1691. Babbage and De le Beche had formulated the general theory of changes of level by contraction and expansion and the rise of continents. Mather, Elie de Beaumont, Lyell and others had made more or less reference to the principle, and M. Constant Provost had published in 1860 his view that the agency of contraction alone will account for the various changes of level which the continental areas have undergone. There were however certain features which were his own, as shown in the following passage:

"The reader will perceive that although the main principles of Provost are sustained by the writer in this and his former paper, the manner in which these principles are carried out, is in some respects a little different, especially in the idea that the oceanic areas have been the more igneous parts of the globe, and for this reason have contracted most; that certain orographic changes over the continents are due to contraction beneath the oceanic regions, and that the fissurings and mountain elevations have for this reason taken place in some instances near the margin of a continent, or near the limit between the great

[1] Am. Jour. Sci. II., Vol. II., p. 355.

[2] Am. Jour. Sci. II., Vol. III., p. 94.

[3] Loc. cit., p. 176.

[4] Loc. cit., p. 381.

contracting and non-contracting (comparatively non-contracting) areas. The efficiency of the cause of contraction has appeared to the writer to be wider and more evident, as the subject has received closer attention; and the study of it very naturally led to modifications of former views."[1]

Thus, it will be seen, that although others had before conceived of the idea of the general effects of contraction, it was to Dana the working hypothesis in the construction of a system of geology.

Although later investigations have added new light for the interpretation of the details of mountain building and earth shaping, a reference to the chief points of the theory, as elaborated by Dana in 1847 will show how much we are indebted to him for a clear exposition of the general principles of the science. In the second article "On Geological Results of the Earth's Contraction" these principles are stated. In regard to the Appalachian Chain, the general structure of which the Rogers brothers had already elaborated, the peculiarities were by them explained as the result of the propelling force or thrust of moving waves of molten material beneath, and the "disrupting tension of the compressed gaseous matter." Mather had previously spoken of the effects of refrigeration of the earth, but he found the cause of the features of the Appalachians in "a paroxysmal elevation and the action of inertia due to the more rapid westward motion of the part of crust lifted up further from the center of revolution." In the article above referred to, Dana wrote, "The principal peculiarity of these plications to which we would ask attention, is the following: the greater abruptness of the northwestern slope of each fold, in connection with the diminution of the undulations to the northwestward; and it will be our endeavor to show that this peculiarity, and the irregularities which exist are necessary results of the action of a force laterally exerted;" and he proceeded to demonstrate how by this power, "a series of folds would be produced each with the inclination steepest on the side farthest from A (the point of resistance); and moreover, these

[1] Am. Jour. Sci. II., Vol. III., p. 179, 1847.

folds would be necessarily most abrupt the nearer they are to A" (p. 184). Further on he gives four chief "reasons why this action should not produce perfectly regular and uniform folds: (1) from a variation in thickness of the bed; (2) from a want of uniformity in the material or its state of induration; (3) from an inequality in the action of the force upon different parts of the line against which it operates; (4) from irregularity in the contraction going on beneath the area." He observed a third principle, viz., that by the effect of gravity alone plication would be produced in much inclined or tilted clayey layers, while the sandy layers unless greatly indurated would settle bodily. A fourth principle is stated thus, "If the material subjected to lateral pressure be not capable of folding, or only partially so, the region operated upon instead of rising into a series of elevations would be raised into one or more ridges of much greater height." A fifth principle is that intruded igneous rocks or dikes may not be the cause, but are rather "a concomitant result of the same general operation." A sixth principle is "the folding of strata by subsidence of the plicated region can be only of small extent." Seventh, he says "the occurrence of volcanoes mostly in the neighborhood of the sea is a necessary result of these principles." The eighth principle is that the grander geological epochs are the direct result of more or less catastrophic periods which would separate, according to the theory, longer periods of comparative quiet, thus forming the transition breaks between the great systems.

While Dana was a consistent uniformitarian, in so far as to interpret past phenomena of the earth's history by the operations of forces such as are now in action, he clearly saw the natural relations of periods of special disturbance of the strata by the reaching of high degrees of tension and their expression in elevation and fractures along lines of tension, and the more quiet periods of chief sedimentation. This principle is better elaborated in the latest edition of the *Manual* than in previous works, on account of the fuller knowledge of the facts finally attained. In the development of the American continent there are recog-

nized, not only long periods of sedimentation and accumulation of strata in synclinoria, but separating these periods of quiet there were revolutions resulting in each case in lifting greater or smaller areas permanently above the surface of the ocean, and the later of these revolutions were the grander, in amount of elevations and mountain making, in fracturing and lava outflows, and in production of volcanoes, because, as his theory explains, of the greater thickness and rigidity of the crustal portion of the earth incident to the secular cooling of the globe.

In the article of 1847 the Appalachian revolution closing the Palæozoic, and what has been subsequently called the Palisade revolution, which terminated the Jura-Trias of the Atlantic border region, are distinctly referred to; and besides these we now know of the Taconic revolution, at the close of the lower Silurian; the Acadian revolution terminating the Devonian in the east; the great Rocky Mountain revolutions terminating the Mesozoic and bringing in the Tertiary conditions in the Laramide elevations, progressing a stage farther in the lifting of the Coast Range region at the close of the Miocene, and finishing its work at the close of Pliocene in the lifting of the Sierra Nevadas. That these more or less catastrophic events were the natural consequences of the continuous uniform cooling and contracting of the crustal portions of the globe, is a corollary of Dana's theory of the earth. As he observed, referring to these revolutions in the last edition of the *Manual*, "the above facts are brought forward to illustrate the grand principle, already admitted by some writers, that such grand crises,—by causing wide emissions of heat and changes of level in the sea, and violent shakings of the globe with its mobile waters,—were in early times a necessary result of the contraction in progress."

Referring to the Appalachian revolution, he wrote, "It is not a matter of surprise that there should have been an abrupt cessation with this event of preëxisting forms of marine life. The period when the effects of dislocation began to be transferred from the oceanic areas to the continents appears to have been the era of this catastrophe, and it was an era of similar changes

in various parts of the globe." The forty-eight years of constant study of the new discoveries in geology and testing the theory has shown it to be founded on fundamental truths of geology. The importance of this one, among the causes producing the changes which have taken place in the history of organisms, is a sufficient reason for here making a lengthy quotation from the fourth edition of the *Manual* regarding the application of this theory. Speaking of the disappearances of life at the close of the Palæozoic, the following is written:

"There was no break in the stream of life, but for the most part only seeming interruptions, and many of these owe their prominence in geological history to the culminations and declines of types that were in progress. But it was an epoch of relatively abrupt change, and if chiefly due to the progressive evolution of new species, as has been urged by some geologists, there must have been for the result a great acceleration in such change in consequence of the physical conditions produced by the orogenic disturbances. But the orogenic movements were local and the biologically transforming effects from such a cause should have been confined to the countries where these movements were in progress. The universality and abruptness of the disappearances cannot therefore be so explained. Very much is left for the destructive effects direct and indirect, that is, the exterminations attending the mountain making.

"The causes of the exterminations suggested by the changes are two: (1) A colder climate over the land, and colder waters in the extra-tropical oceans, for the emergence of the eastern semi-continent of North America and of large lands in the other continents could not fail to lower somewhat the temperature of the whole globe. With a lower temperature, the currents from the north sweeping along the coasts would have been destructive to the marine species living in the waters. (2) Earthquake waves produced by orogenic movements. If North America from the west of the Carolinas to the Mississippi Valley can be shaken in consequence of a little slip along a fracture in times of perfect quiet, and ruin mark its movements, incalculable violence and great surgings of the ocean should have occurred and been often repeated during the progress of the flexures, miles in height and space, and slips along newly opened fractures that kept up their interrupted progress through thousands of feet of displacement. The

Acadian upturning took place on the ocean border, and the Appalachian was not far distant from it, Arkansas, moreover, added to the extent of the belt of disturbance. Under such circumstances devastation of the sea border and the low lying land of the period, the destruction of their animals and plants, would have been a sure result. The survivors within a long distance of the coast line would have been few. The same waves would have swept over European land and seas, and there found coadjutors for new strife in earthquake waves of European origin. These times of catastrophe may have continued in America through half of the following Triassic period, for fully two-thirds of the Triassic period are represented by rocks and fossils on the Atlantic border" (p. 736).

Thus the course of the evolution of the life on its surface was in no small way dependent upon the gradual contracting of a cooling globe.

Not only did Dana take this broad and comprehensive view of the whole system of geological phenomena, but he made a thorough and particular study of several of the more difficult problems of American geology; among them may be named the interpretation of the glacial phenomena over New England and the classification of the period for North America—the solution of the "Taconic" controversy, and the associated questions of metamorphism and mountain building.

When the first edition of the *Manual* was issued (1863) there was far from unaniminity of opinion among American geologists as to the agency by which "drift" gravel and bowlders had been spread over the surface of the more northern states of the Union.

Dana interpreted the "drift" and the striations on the surface of the rock to be evidences of glaciation, and he was an earnest advocate of the theory of a great continental glacier, as opposed to the iceberg theory. Although few of the present generation have ever held another opinion, some of us will remember the strenuous defense of the iceberg theory so lately as the meeting of the American Association of Science at Montreal. Professor Dana not only opposed that theory from the beginning, but by his indefatigable personal studies of the surface topography and markings in the Connecticut Valley, and

particularly in and about New Haven, as well as with less minuteness, over much of New England and in parts of New York state, accumulated the evidence, which has not only thoroughly proven the glacial theory, but has furnished the greater part of the fundamental facts upon which is built the present classification of the glacial period as given in his *Manual*. To be sure, many other workers have furnished abundant contributions and have greatly elaborated these facts, but when we examine the literature and observe the part Dana took, in formulating the grand outlines as well as many of the particulars of our general theory of the glacial period in America, we find his part in laying the foundation of opinion was far greater than that of any other one man.

His papers in the *American Journal of Science*, beginning in 1863 and not ceasing till the year 1893, are numerous, and are based upon his personal observations in the field. They cover the discussion of each of the important questions which enter into the present theory of the glacial period. Such were: the directions of striæ and their relations to topography, with the establishment of the fact of their local deflection to follow the course of larger valleys, as the Mohawk, the Hudson Valley, the Connecticut River valley, etc.; the floods resulting from the melting of glaciers and the nature of evidence left by them; the absence of marine life in Long Island Sound through the glacial and part of the Champlain period; reindeer of Arctic type in southern New England; depression of land during the melting of the great glacier; damming of streams by ice; and Kames and their relations to the ordinary materials of drift. These, and many others of the particular phenomena of glaciation were built into the definition of the glacial period as he elaborated it from his personal observations.

Even to his last days his interest in the glacial question was keen and wide. In the preparation of the fourth edition of the *Manual*, although confined to New Haven, he made a thorough revision of the chapters on that subject. He realized that outside his quiet study hot controversies were going on among gla-

cialists of different opinions in America, and he took the greatest pains to get from original sources the evidence on both sides. He opened the pages of the *Journal of Science* to discussion of both views. His correspondence was widely extended, and with, I presume, every one of those who had taken a prominent part in the discussions of the past few years. In a conversation with the writer on one of those days, he remarked that one of the chief causes of contrary opinions regarding the division of the glacial period in America was, he believed, due to local coloring resulting from taking either the phenomena of New England and the eastern edge of the glacier, or else those of the western-central region, as the standards of judgment by the two sides in the discussions.

When he had finished the pages on the quaternary for the printers, he remarked that he had reached an explanation of the events which he thought would harmonize the divergent views, and he expressed more than ordinary enthusiasm, and spoke as if, having exhaustively compared all the facts that had been brought forward, he had reached what he believed to be the true solution of the vexing problem.

His explanation of the case, viz., an epoch of extreme advance, which was of great length, with, following, an epoch of first retreat, then halt, in which the deposits of the Lafayette formations were being made on the gulf and eastern borders, and with, third, the epoch of final retreat of the ice from the northeastern plateau, is certainly a comprehensive interpretation of the series of phenomena as a whole, however it may be modified by increasing knowledge. (See *Manual of Geology*, 4th ed., pp. 943–80.)

The clearing up of the confusion involved in Emmons' "Taconic System," was another task to which Professor Dana gave enthusiastic attention. After some thirty years of defense of the system by its friends, against the ineffective attacks of those who were unable to bring convincing proof of its fallacies, Professor Dana entered the field in 1871. The main trouble was that Emmons' interpretation was based upon several false tenets which were then maintained by the best of geologists; and it was

necessary to demonstrate their falsity before they could be laid aside. Prominent among them was the belief, that the age of a rock can be determined by its lithological characters. In the absence of fossils, the granular quartz was thus determined to be metamorphozed Potsdam Sandstone, and both Cambrian and Hudson River Slates were included under the name Taconic Slates, and supposed to be of pre-Cambrian age. A second error was the belief that the presence of certain minerals may be relied upon for identifying horizons—and a third point, which though known to be false, was too much trusted in even by those who knew better; viz., that actual succession of rocks in a metamorphozed region is a safe-guide in determining the order of sequence. In 1871 Professor Dana entered the field determined to settle the disputed questions by study of the region itself. "My purpose," he wrote, "was (1) to prove the continuity from north to south of the three associated Taconic formations, the quartzite, the limestone and the slates or schists; also (2) to work out the system of flexures; (3) to ascertain whether the Taconic mountains were generally or not of synclinal structure, as they were made by Rogers, Mather and Hall, and in 1864 by Logan; (4) to settle the question as to continuity from east to west of the limestones of the different north-and-south belts; (5) to apply the evidence from fossils, making them the sole basis for fixing the age of the beds; and finally (6) to use the evidence of the age, thus obtained, for the determination of the age of the hydromica schists, chloritic schists, garnetiferous and staurolitic schists, and other rocks of the Taconic Mountains, and thus test the value of, or give greater precision to, the assumed 'lithological canon' first propounded by Emmons. My work was continued in western New England and eastern New York at intervals from 1871 to the close of the season of 1886." The results of these investigations are continued in a number of papers in the *American Journal of Science*, from 1871 to 1888. Among the more important of them are the following, viz.: "What is true Taconic?" "Green Mountain Geology: on the quartzite" in 1872; "On the Quartzite, Limestone and asso-

ciated rocks of the vicinity of Great Barrington, Berkshire Co., Mass.," 1872–3; "An account of the discoveries in Vermont geology of the Rev. Augustus Wing; the relations of the geology of Vermont to that of Berkshire," 1877; "The Hudson River age of the Taconic Schists," 1879; "The geological relations of the Limestone belts of Westchester Co., New York," 1880–81; "On the Southward ending of a great synclinal in the Taconic Range," and "The Corlandt and Stony Point Hornblendic and Augitic rocks" in 1884; "Taconic rocks and stratigraphy," 1885, 1886 and 1887; "Lower Silurian fossils from a limestone of the original Taconic of Emmons," 1886; and the final paper of the series, "A brief history of Taconic ideas," in 1888. In addition to the above are "Two atlases, one of Berkshire Co., Mass., and the other of Westchester Co., New York, having on the back the title 'Taconic Rocks,' containing my [his] notes made in the geological survey of these regions," which were specifically bequeathed by his will to the Library of Yale College.

The solution of the problems was not alone Dana's work: the fossils discovered by Wing, Billings, Dale, Dwight, Ford, Bishop, Walcott and others were the evidences which finally redistributed the various members of Emmons' system into their proper places in the standard systems of the Palæozoic already defined. But as we look back over the battle and trace its progress, it is evident that the energy and thoroughness with which Professor Dana attacked the problems, if he did not do all the work, availed much in inspiring and directing the work of others; the bearings and importance of whose discoveries he was often quicker to discern than the discoverers themselves, and always gave full credit to whomsoever it was due. The final paper, "A brief history of Taconic ideas," is an admirable example of the calm judicial spirit with which he was accustomed to rise above all personal prejudices and individual opinions and to define scientific facts as they are.

Two other problems which grew out of the investigations already mentioned were, the interpretation of the partially metamorphosed rocks of the Connecticut Valley, and that of the

greenish schists on the western border of the Triassic in southern Connecticut.

Two papers were written upon the first subject, viz.: "On the rocks of the Helderberg era, in the valley of the Connecticut," 1873, and "The Helderberg formation of Bernardston, Mass., and Vernon, Vermont," 1877. The fuller elaboration of the stratigraphy and of the fossil contents were made by Professor B. K. Emerson of the Massachusetts survey. The other problem, about which the paper on "The 'chloritic formation' on the western border of the New Haven region," in 1876, and remarks in the "Geology of the New Haven region," 1870, opened the discussion, was not satisfactorily finished at the time of his death. It involves questions in metamorphism which call for petrographical as well as geological investigation, and whose solution must be left for other workers.

The preparation of the *Manual of Geology* was perhaps the greatest of his contributions to geology; of its value every geologist of America knows. It has done more to unify and codify American geology than any other work, and until very recent years, if we may judge from their literary quotations, foreign geologists have made Dana's *Manual* their chief source of information regarding the geology of America. It has always been characterized by that accuracy, and that fullness of details collected with a rare selective judgment, which has made it for every worker an indispensable handbook. In the last edition, which was finished but a few months before his death, he has combined the results of personal revision by the active workers in the more recently explored fields, with his own full knowledge of the current literature, to make it a complete account of the state of the science at the time of its publication.

In the breadth and richness of his knowledge an equal to Professor Dana is not likely to arise. For the thoroughness and industry which he applied to all his investigations, the fairness with which he treated all with whom he could not agree, the kindness and consideration he showed to all, and the unswerving devotion to the truth, James Dwight Dana will be long remem-

bered by all students of science. His geological contributions to American geology constitute such a fundamental part of our knowledge that so long as the science endures he cannot be forgotten.

HENRY SHALER WILLIAMS.

NEW HAVEN, 1895.

GLACIAL AND INTER-GLACIAL DEPOSITS NEAR TORONTO.

A LONG line of yellowish white cliffs to the east of the city forms a striking feature of the voyage across Lake Ontario from Niagara to Toronto; and a closer examination of the Scarboro' Heights discloses a most interesting section of the drift. At the highest point the cliffs rise more than 300 feet above the lake, and the thickness of the deposits is probably considerably greater than this, for the solid rock nowhere crops out in a distance of twenty miles. Along many parts of the Heights, which are in all nine and a half miles long, reaching from a point three and a half miles east of the River Don to the mouth of Highland Creek, the undermining action of the lake provides for a constant series of fresh exposures; and at other points the deep V-shaped valleys of small streams, afford almost as good sections. From Scarboro' westwards to Toronto also, the cuttings for railroads and streets, and the ravines of the Don and its tributaries display more or less complete sections of the drift, some of them more than 150 feet in height.

The Scarboro' Heights were an object of interest to engineers and geologists more than forty years ago as the source of the sand which, driving westwards along the lake shore, is arrested by the current of the River Don, thus forming the island which protects the harbor of Toronto;[1] but no serious geological study appears to have been made of them except by Dr. George Jennings Hinde, who published an admirable account of them in 1878.[2] The results of his observations seem little known, probably from the fact of their having been published in a journal not very widely circulated and at a time when glacial studies did not

[1] Reports on the Improvement and Preservation of Toronto Harbor, Prof. Henry Youle Hind, p. 1; Sandford Fleming, p. 15; Appendix to Canadian Journal, 1854–5.

[2] Glacial and Inter-glacial Strata of Scarboro' Heights, Can. Journ., 1878, p. 388, etc.

attract so much attention as they now do, since the rise of a body of able and ardent glacialists in America as well as the Old World.

The inter-glacial beds of the Don have been described briefly by the present writer[1]; but beyond these two papers little has appeared as to the drift in this part of Ontario. It seemed so difficult to correlate the results obtained from these two localities only a few miles apart, that it was decided to connect the two by a careful study of the whole ground. This has now been carried out with tolerable completeness, and it is proposed here to give a short account of the results. In doing the work great assistance has been received from the authorities of the Grand Trunk and Canadian Pacific Railways, who provided profiles of all the lines near Toronto; from the city engineer, who provided maps; and from several specialists who have determined fossils obtained from inter-glacial beds; and I desire to express my heartiest thanks for their great kindness.

It will be well to begin with an account of the Scarboro' Heights which afford the thickest and most complete section in the region. For this my own observations, which in general accord well with those of Dr. Hinde, will be made use of chiefly.

The drift deposits show themselves first, after a long stretch of gravel beach, about three and a half miles east of the Don, as a low cliff of stratified sand and sandy clay, below which blue till appears. The first outcrop is just west of Victoria Park, and the escarpment, which is only ten or fifteen feet high at the beginning, rises rapidly, after a break caused by the valley of a stream, to one hundred and sixty or eighty feet. About three and a half miles east of the Park the cliff suddenly rises to a height of more than 300 feet, but soon drops down to its old level, after which it sinks gradually to a height of twenty or thirty feet, six miles farther east, where it is interrupted by the valley of Highland Creek.

At its best exposures the escarpment displays, beginning at the level of the lake, about ninety feet of stratified clay, followed

[1] Inter-glacial fossils from the Don Valley, Am. Geol., Feb. 1894, p. 85, etc. In this paper references are given to the literature on the subject, which is very scanty.

Section at Scarboro' Heights, 9½ miles long and 300 feet high.

by fifty feet of stratified sand, covered by a bed of till varying from forty feet to nothing in thickness. Three miles from Victoria Park this layer of till suddenly dips down to the lake, thickens to sixty or seventy feet, and rises as suddenly a quarter of a mile farther east. The hollow left on its surface is filled with stratified clay to a depth of ninety feet, and this is followed, where the escarpment is highest, a half mile farther east, by from seventy to one hundred feet of stratified clay and sand, capped by twenty or thirty feet of an upper till. About one hundred feet of stratified sand overlying the western end of the lower sheet of till, should perhaps be correlated with this, though possibly of post-glacial age. These sands thin out to nothing where the upper stratified clay shows itself. The accompanying diagram, in which the heights are exaggerated tenfold, will give a general idea of the section and make a more elaborate description unnecessary. It will be noticed that the lower bed of till dips down to the lake at each end of the section; while the upper till, forming the surface of a table land which comes out to the escarpment for a short distance only, is cut off abruptly at each end.

Examining the members of this section in ascending order, we find at its base a series of bluish-gray clays rising out of the lake. They lie perfectly horizontal, are often finely laminated with sandy partings, having sometimes twenty laminæ to an inch, but at other times forming beds several feet in thickness. Narrow bands of flat green concretions of impure carbonate of iron occur at various levels; and at others thin layers of peaty matter. Some beds of clay richer than others in plant food may be followed long distances by the eye as bands of rich, green vegetation, while other parts are bare.

The peaty matter varies from a mere film to a thickness rarely greater than half an inch, and is made up sometimes chiefly of mosses, but more commonly of fragments of bark, wood and twigs, waterworn and mingled with flakes of mica. Quite seldom one may find a larger knot or broken branch, but never trunks of any size. From these insignificant peaty layers Dr. Hinde obtained three species of diatoms, a chara, five mosses, Bryum, Fontinalis, Hypnum commutatum, H. revolvens (?) and another species of hypnum, spores of lycopodium, pieces of pine and cedar wood, portions of leaves of rush, etc., and seeds of various plants. Among animals he found two or three species of Cypris, a Planorbis and a Zonites (doubtful), as well as the elytra of beetles.[1] The insect remains were submitted to Dr. Scudder, who reports as follows:[2]

"Among the material . . . . . was a considerable number of the elytra and other parts of beetles, an assemblage, indeed larger than has ever before been found in such a deposit in any part of the world, and they are mostly in excellent condition. Twenty nine species have been obtained, some of them in considerable numbers. Five families and fifteen genera are represented; they are largely carabidæ, there being six or seven species each of Platynus and Pterostichus and species also of Patrobus, Bembidium, Loricera, and Elaphrus. The next family in importance is the Staphylinidæ, of which there are five genera, Geodromicus, Arpedium, Bledius, Oxyporus, and Lathrobium, each with a single species. The Hydrophilidæ are represented by Hydrochus and Helophorus with each one species; and the Chrysomelidæ by two species of Donacia. Finally a species of Scolytidæ must have made certain borings under the bark of juniper.

"Looking at them as a whole and noting the distribution of the species to which they seem to be most nearly related, they are plainly indigenous to the soil, but would perhaps be thought to have come from a somewhat more northern locality than that in

[1] Can. Jour. 1878, p. 399.

[2] Fossil Insects of North America, Vol. II., Tertiary, p. 40.

which they were found; not one of them can be referred to existing species, but the nearest allies of not a few of them are to be sought in the Lake Superior and Hudson Bay region, while the larger part are inhabitants of Canada and the northern United States, or the general district in which the deposit occurs. In no single instance were any special affinities found with any characteristically southern forms, though several are most nearly allied to species found there as well as in the north. A few seem to be most nearly related to Pacific forms, such as the Elaphrus and one each of the species of Platynus and Pterostichus. On the whole, the fauna has a boreal aspect, though by no means so decidedly boreal as one would anticipate under the circumstances."

It will be seen that this remarkable assemblage of insects is of great importance in coming to a conclusion as to the climate of the time when these deposits were laid down; and Dr. Scudder's wide experience in regard to the geographical range of North American insects gives special value to his views on the subject.

By washing, drying, and examining with a lens peaty matter from Scarboro' the present writer has succeeded in obtaining a large amount of additional material, consisting of wing cases and other parts of the chitinous armor of insects, all of which has been submitted to Dr. Scudder, who has very kindly consented to determine them and thus add to the data available for judging of the climate.

A considerable number of determinable parts of plants, such as leaves, seeds, mosses, etc., obtained in the same way, was sent to Dr. Macoun of Ottawa. The small collection of mosses was forwarded by him to Mrs. E. G. Britton of Columbia College, New York; and I am much indebted to both of them for the trouble they have bestowed on the determinations. Dr. Macoun gives the following list of the species determined by him in the material sent: Larix americana (?), Abies balsamea, Salix, alder, Carex aquatilis and C. utriculata, Equisetum, Oxycoccus vulgaris and vaccinium uliginosum. Of the last two he is quite certain.

Mrs. Britton determines the mosses as follows: Limnobium

palustre (?), L. montanum (?), Hypnum lycopodioides (?), H. aduncum, H. fluitans (?). Professor Penhallow of Montreal has determined two specimens of wood from Scarboro' as probably Picea nigra.

It will be noticed that the plants obtained by myself differ considerably from the list given by Dr. Hinde, perhaps because taken from different levels in the clay. Doubtless the number of species could be greatly added to by careful search.

Looking at the plants as a whole Dr. Macoun is of opinion that the climate was like that of the northern part of the Gulf of St. Lawrence or southern Labrador, cool and wet. He states that all the species are represented in the herbarium of the Geological Survey at Ottawa by specimens from the regions mentioned; and thinks that the deposit was formed in a pool surrounded by trees, such as we find in our northern woods today. Dr. Macoun's conclusions regarding the climate as determined from the plants correspond fairly well with those of Dr. Scudder; so that the question may be looked upon as settled. There are, however, no evidences of the action of ice. Dr. Hinde remarks the complete absence of pebbles or bowlders from these clay beds, a point which the present writer also has been struck with, suggesting no transport and dropping of materials by floating ice. One may infer from the uniform lamination and fineness of the clay that it was deposited in quiet water some distance from the shore. Leaves and bits of bark and mosses drifted in by the wind or brought down by a stream gradually waterlogged and sank along with the slowly settling flakes of mica and fragments of insects. It appears that forest fires raged in Ontario then as now, for fragments of charcoal or of chips charred on one edge are not infrequently found mixed with quite uncarbonized woody material. This, of course, does not necessarily imply the presence of man; for doubtless many fires have originated by natural causes, such as lightning.

Resting conformably on the clay we find about fifty feet of fine, yellowish or grayish sand, sometimes having thin layers reddened with garnets or blackened with magnetite. Very

marked transverse bedding is often observed, indicating more troubled water than during the deposit of the underlying clay. Some parts of these sands contain many nut-brown concretions of a much rounder form than those from the clay. A large number of these were broken, but only two or three contained traces of vegetable matter or portions of insects as a nucleus. Peaty matter may be found in small amounts in the sand, and at a few points fresh-water shells were found along with the concretions, Sphærium striatinum and Succinea obliqua, according to determination of Mr. C. T. Simpson. The Succineas seem almost too fresh and well preserved to be of inter-glacial age, but they are found nowhere except in the sand beds below the lower till, and the evidence of their age seems pretty conclusive.

The beds just described were deposited in water having a level at least 140 feet above that of the present Lake Ontario; and they may have been considerably thicker than we find them now, for there is clear evidence that they were greatly eroded before the overlying till was spread out. At the Dutch Church not only the sands but the stratified clays also were cut through by a stream valley, for we find the bowlder clay filling a hollow that reaches below the level of the lake. Hinde supposes that the ice of the glacier ploughed out this deep valley; but there is no reason to suppose that this portion only should have been excavated by the ice front while the same materials were left untouched on each side. The bedding of the clay is scarcely disturbed right up to the contact with the till, which would be impossible if the snout of the glacier had ploughed its way through, but is intelligible if it simply filled a preëxisting valley.

The till which follows is of the usual description, a blue calcareous clay charged with polished and striated pebbles of limestone and black Utica shale, with a few Laurentian bowlders. This bed of till is continuous from end to end of the section except at a point about one mile and a half east of Victoria Park, where probably by subsequent erosion, it is thinned out to nothing for about 300 yards. There is a deep hollow in the till at the Dutch Church, where it dips down to the lake, perhaps an

original depression of its surface, now filled with ninety feet of stratified clay, very like the lower beds, but more calcareous and apparently free from fossils and concretions.

At the point where the upper terrace comes out to the shore these stratified clays are covered conformably by a series of stratified sands with some clay beds, in all seventy feet thick. Several of these beds at different levels are remarkably crumpled and contorted, while the beds immediately above and below appear quite undisturbed. They have perhaps been folded by

Upper part of Section at Scarboro' Heights, showing two upper layers of till and the crumpled strata. After photograph by Dr. Ellis.

the grounding of ice floes, and in appearance they remind one of examples figured in *Geikie's Great Ice Age*.[1] No fossils have been obtained from these inter-glacial beds.

The upper till, which overlies the country to the north of the Scarboro' Heights, forming a gently rolling table-land, described by Professor Chamberlin in conversation as a mild form of moraine, is seen at this section to consist of yellowish-brown clay with well striated pebbles and larger stones, fragments of black Utica shales, often falling to pieces, limestones apparently of Trenton age, and archæan rocks, such as gneisses. It differs from the lower till in being somewhat more sandy, and especially in hav-

[1] P. 271–2.

ing been greatly weathered, some parts at the bottom alone showing the original blue color of the clay.

West of this highest part of the escarpment a series of rather coarse, cross-bedded, stratified sands and gravels, in which no fossils have been found, overlies the lower till, at first in a a thin layer, but rapidly thickening as the bed of till descends toward the lake near Victoria Park, where it expands to a thickness of more than one hundred feet. Hinde looks on these sands and gravels as post-glacial, but similar deposits a few miles to the west and north are covered by the upper till; and at a cutting on the Scarboro' street railway a little north of the Park crumpled strata of the kind previously referred to are well exposed, suggesting an inter-glacial age for these beds. However up to the present their position must be looked on as not positively settled.

A comparatively thin layer of coarse gravel and well-rounded stones, followed by loamy soil covers these sands and forms the surface of the Iroquois terrace.

From the description just given it will be seen that at the Scarboro' Heights there are two beds of till separated by a deposit of unfossiliferous stratified clay and sand amounting in thickness, if we add the depth of stratified clay at the Dutch Church to that of sand and clay at highest points a little farther east, of 160 feet. Below the lower till the fossiliferous sands and clays have a depth of at least 140 feet, their lower limit being covered by the lake. Dr. Hinde assumes a third till below the lower clay, nowhere exposed along the Scarboro' escarpment, but cropping twelve miles to the west at Humber Bay, where till overlies the Hudson River shales, and is covered by stratified clay not unlike that at Scarboro'. The Humber clays, so far as I have observed, do not contain peaty matter nor the plate-like concretions of clay-iron stone; however, they are so far separated that the conditions under which they were deposited may have differed greatly from those at Scarboro'.

Whether the underlying till be found or not, there is every reason to think the lower Scarboro' sands and clays inter-glacial; for they contain a series of minerals including garnet, magnetite,

hornblende and biotite, thoroughly characteristic of Laurentian rocks and not found in the adjacent Hudson River or Utica shales. The transport of these materials for a distance of not less than seventy miles is best accounted for by glacier ice.

The extent of these deposits has not yet been worked out in detail, though the lower stratified clay was apparently widespread. Twenty feet of clay very like it, containing thin layers of peaty matter, may be seen on the shore of Lake Ontario four miles to the east of Highland Creek, here also covered by a bed of till. Exactly similar clay occurs about four miles to the northwest of Victoria Park in the brickyards of Messrs. Price and Logan. The exposures are excellent, one presenting a face of sixty feet; and the top of the clay, which rises about one hundred feet above Lake Ontario, is covered with a few feet of stratified sand. One finds the greenish plate-like concretions, and peaty matter containing mosses, pieces of bark and wood, elytra of beetles, flakes of mica, etc., just as at Scarboro'. The layer of till is wanting at these brickyards, but is found a few hundred yards farther north near the corner of Danforth avenue and Greenwood lane.

If we include the Humber clay in the series, this lacustrine deposit has a length of twenty two miles, by a breadth of at least one and one half miles. Omitting the Humber beds, it has been traced for about sixteen miles.

The upper, unfossiliferous clay from the Dutch Church seems also very widely distributed. It may be found as suggested by Dr. Hinde, in the north of Toronto (formerly Yorkville), where it is used to make gray brick. It seems to occur also at the Don Valley brickworks, and other points along the Don ravines. Similar stratified unfossiliferous clays making white or buff or gray brick occur at various points a few miles to the north and west of Toronto; and beds very like them underlying an upper till are well exposed on the lake shore between Newcastle and Newtonville, more than forty miles to the east. The upper unfossiliferous clays appear then to be even more widely spread than the lower peaty clays, though one can hardly make sure

that the deposits at all the localities mentioned were laid down in the same body of water and at exactly the same time.

The inter-glacial deposits on the Don, best shown at the brickworks owned by the Messrs. Taylor, were described a year ago,[1] but will be referred to again, giving the results of a careful reinvestigation under better conditions.

When it was examined in the preparation of the paper referred to, the quarry consisted of two parts, a lower one showing about forty feet of drift, including nearly three feet of till resting on Hudson River shale, twenty-five feet of stratified sand with one or two clay beds, and, above this, ten feet of stratified clay making red brick. A slope of grass extended from this part of the quarry for about one hundred yards to the upper portion, where about forty feet of stratified clay making buff brick were to be seen, the top of the exposure reaching almost to the level of the plain formed by the Iroquois beach of Spencer. The part covered with grass was stated by the men at work in the quarry to consist of the same clay as that worked for buff brick, and was included with the upper stratified clay in the section given. About a third of a mile northwest of the quarry, the Davenport Ridge, a morainic tract of gently rolling highland, composed of somewhat sandy till containing bowlders and striated stones, comes to a sudden stop and forms a cliff fifty to seventy feet high at the Iroquois beach. That the Davenport till stretched much farther south before the Iroquois water had encroached upon it is clear, not alone from the steep cliff, but from the immense bowlders scattered over the terrace, evidently left behind when the finer materials were washed away by wave action. Such bowlders lay on the surface just above the quarry, until removed a year ago. The fact that the upper stratified clay of the quarry may be traced here and there up the ravine to the north, until, about half a mile above the brickyard, it underlies the till of the Davenport ridge, confirms the conclusion.

The Davenport ridge is a continuation of the mild moraine

[1] Inter-glacial fossils from the Don Valley, Am. Geol. Vol. XIII., February 1894, p. 85–95.

forming the upper plateau at Scarboro', the two being separated only by the deep bay-like depression of the Don Valley; and it seemed to me probable, last year, that the layer of till overlying the shale at the brickyard was a continuation of the lower Scarboro' till, which sinks beneath Lake Ontario near Victoria Park three or four miles to the east. This implied that the fossiliferous beds at the Don, with the overlying stratified clay in which no fossils occur, were equivalent to the upper, unfossiliferous beds at Scarboro'. This spring, however, new excavations at the brickyard have completely overturned this theory by disclosing a thick bed of till in the slope formerly covered with grass. This overlies the fossil-bearing strata which correspond, therefore, to to the lower, fossiliferous bed at Scarboro', so far as position is concerned.

At present the quarry presents the following section, as measured by aneroid and steel tape:

	Feet.
Soil and stratified clay, making buff brick (unfossiliferous)	43
Till (partly covered with grass) about	35
Stratified clay with peaty matter, making red brick	13
Stratified sand with some clayey beds (fossiliferous)	24
Till	2
Hudson River shales, about	60

The Hudson River shales rise about thirty-five feet above the level of Lake Ontario. At the Don Valley brickworks we have, then, a lowest till resting on the rock and overlaid with fossiliferous beds; a second till corresponding to the lower Scarboro' till; but no uppermost till, though one probably existed before the formation of the Iroquois beach, and the upper stratified clay passes beneath the upper till at the Davenport ridge a half-mile away. So far as I have observed the three tills are nowhere all disclosed in a single section; but a shaft sunk through the Davenport ridge or the highest part of the Scarboro' Heights would probably cut through all three.

Since the paper on the Don fossils was published three new localities have been found in the same valley; one of them, which was opened to give employment to the convicts at the gaol

near by, proving especially interesting; since thin layers of matted deciduous leaves occur in it. One of these localities is at the shore of a pond a mile above the brickyard, so that the fossil-bearing sands and clays have been shown to extend for three miles along the valley of the Don. Judging by the position of these beds with reference to the lake, the stream in which they were formed had a much more rapid fall than the present sluggish river. The lowest fossil bed in the upper part of the valley

Quarry at Taylor's brickyard, Don Valley, Toronto. The section shows the Hudson River shale; the lowest till resting on it (dark); the fossiliferous stratified sand and clay; the middle till just beneath the grass at the staging; and the upper stratified unfossiliferous clay in the much foreshortened upper quarry. The photograph is by Dr. Ellis, of the School of Practical Science, Toronto.

is about forty feet above the lake; at the Convict Cutting ten or fifteen feet; while at the cutting for the Don improvements, near the mouth of the present river, fossils were found several feet below the level of Ontario.

The localities most productive in fossils are the brickyard and the Convict Cutting, and a brief description of them may be of

interest. At the brickyard unios, retaining their dark epidermis and having the valves united, are often found embedded in a few inches of blue clay immediately overlying the till. The sands above this contain more or less waterworn unios, pleuroceras, sphæriums, etc., while the overlying stratified clay beneath the middle till holds a little peaty matter, but nothing well enough preserved to be determinable.

At the Convict Cutting, too, the unio bed is disclosed, but some stratified, sandy clay beds in the upper part of the section have proved much more interesting, that patient collector, Mr. Townsend, having obtained from them a large number of leaves, among which he thinks are leaves of the oak, beech and willow. It is very difficult to preserve these leaf fragments, since the clay dries up and the brown traces of the outline and veining shrivel up and become almost unrecognizable.

Up to the present the unios have proved the most important finds along the Don. They include the Unio phaseolus, U. clavus, U. pustulosus, U. pustulosus, var. schoolcrafti, U. occidens (?), U. luteolus, U. undulatus, U. rectus, U. trigonus, and U. solidus. The other shells obtained are Sphærium striatinum, Pleurocera subulare, P. elevatum, an undetermined species of the same genus and a single specimen which may be P. pallidum, Physa ancillaria and Amnicola limosa. I am indebted to Dr. Dall and his assistant, Mr. C. T. Simpson, for the determination of the above species, all of which occur at the brickyards and several of them at the other points. A few other fossils, including one or two species of ostracods, a number of elytra of beetles and one or two teeth, the latter found by Mr. Townsend, have been obtained at the Convict Cutting with the leaves, but have not yet been determined.

The plants include fragments of tree trunks, leaves, a very few mosses and chara. The specimens of wood have been determined by Professor Penhallow of McGill to be Fraxinus quadrangulata, Quercus obtusiloba, Ulmus americana, Maclura aurantiaca and Picea sitchensis (?). Some leaves sent from the Convict Cutting he considers to be of willows and poplars. Pro-

fessor Penhallow had previously found in material sent by Mr. Townsend from the Don Improvements, Asimina triloba, Ulmus racemosa, Taxus baccata and a new maple leaf, which was named Acer pleistocenicum.[1] In respect to the woods, Professor Penhallow says that they are usually badly decayed, but that he has referred them to the nearest living species.

If we compare the inter-glacial fossils of the Don with those of Scarboro' we find them surprisingly different. Up to the present only one species of animal, Sphærium striatinum, a form having a wide range, has been shown to be common to both localities. It will be of great interest to learn if Dr. Scudder finds insects from the Convict Cutting the same as those from Scarboro' or not. No two trees are undoubtedly alike, though Picea nigra of Scarboro' is not far removed from Picea sitchensis of the Don; and willow leaves of undetermined species have been found in both places.

It will be remembered that both the insects and plant remains of Scarboro', in the opinion of such good authorities as Dr. Scudder and Dr. Macoun, point to a cool climate like that of Lake Superior or Labrador; while the Don fossils, on the other hand, point equally conclusively to a climate as warm as that of Toronto at present, if not considerably warmer. The numerous unios, some of them no longer found in our lakes, though common farther south in the Mississippi drainage system;[2] the forest trees including three species (Asimiana triloba, the osage orange and Fraxinus quadrangulata) now belonging to the portions of Ontario along Lake Erie and the states to the south,[3] hint at a climate very far from glacial, probably comparable to that of Ohio at present.

There seems no doubt also that both of these deposits are inter-glacial and included between the same sheets of till; though the lowest till is out of sight below the lake at Scarboro'. These two series of beds can hardly have been formed contempora-

[1] Bull. Geol. Soc. Am., Vol. I., p. 328.

[2] C. T. SIMPSON, Proceedings U. S. National Mus. Vol. XVI., pp. 591–5.

[3] DR. MACOUN, Forests of Canada, Trans. Royal Soc. Can., Sec. IV., 1894, p. 11.

neously; one must have preceded the other; but which came first is not easy to decide.

One might assume that the Scarboro' clays were formed first, a cold climate continuing for a long period of time after the departure of the earliest ice sheet; that the water was drained off or the land elevated afterwards, and the Don of those days excavated its comparatively wide and deep valley apparently not greatly different from the present one. Meantime the climate had become warm, and southern forms of life pushed their way northward and occupied the river and its shores until the second advance of ice destroyed them. This hypothesis seems to agree with many of the facts, particularly if Dr. Hinde is correct in his belief that the stratified clay resting on till near the mouth of the Humber is a continuation of the fossiliferous Scarboro' beds. The quite similar clays at Price's brickyard would then be a remnant of a wide sheet of such lacustrine deposits afterward eroded by the Don. There is an appearance of interbedding of a thin layer of the peaty clay at the Taylors' brickyard with the bowlder-clay above; while the upper fossiliferous beds at Scarboro' were much eroded before this sheet of till was laid down, facts which perhaps point in the same direction. If this hypothesis be correct the Don beds, being much later than those of Scarboro', may somewhere be found resting unconformably on their eroded surface. Up to the present, however, no such section has been observed.

On the other hand one might suppose that the Don beds are the older; that after the till was laid down there was a sudden change of climate, and that southern forms of life quickly followed up the retreat of the ice-sheet as it vanished under the action of warm sun and winds. The fact that Mississippi unios lived and died right on the unweathered surface of the blue till at the brickyard fits best with this assumption. If there had been a long period of erosion before they arrived, one would expect to find the till weathered brown and its enclosed pebbles of shale crumbled to pieces, instead of being fresh and sharply striated. Taking this view, the layer of peaty clay just beneath the middle

till at the Don is the equivalent of the ninety or more feet of peaty clay at Price's brickyard and Scarboro'; and one might expect to find the unio bed, or its equivalent as to climate, beneath the level of the lake at Scarboro'. It should, however, be observed that up to the present no species has been shown to be common to the peaty beds of the Don and those of Scarboro', except one ubiquitous shellfish. It may be that future excavations will settle which hypothesis is correct; if, indeed, some entirely different interpretation may not be put upon the facts described.

Two very interesting articles have appeared recently, one by Professor Chamberlin in the JOURNAL OF GEOLOGY, the other by Mr. Warren Upham in the *American Geologist*, referring to the succession of glacial deposits in America, and mentioning the Toronto inter-glacial beds in that connection. Professor Chamberlin gives the "Toronto Formation" tentatively an independent position as the possible equivalent of Geikie's Neudeckian,[1] and places it in the interval between the Iowan and Wisconsin sheets of till. Mr. Upham places the Toronto inter-glacial beds in a somewhat similar position, but looks upon them as only in a limited sense inter-glacial, "since they lie between deposits of glacial drift; but they seem better referred to moderate oscillations of the ice boundary during its general retreat after the Iowan stage, that is, to a time during the Wisconsin or moraine-forming stage rather than to distinct glacial epochs."[2] He supports this view by a statement as to thinning out of the beds of till between Scarboro' and Toronto, suggesting the nearness of the ice border; and finds the deposits "quite inexplicable on the hypothesis that these till formations record great readvances of the ice, as either to the Iowan stage or to the Wisconsin moraines."[3]

In regard to the thickness of the sheets of till it may be mentioned that they vary greatly in this respect within short

[1] JOURNAL OF GEOLOGY, Vol. III., No. 3, pp. 273–275.

[2] Am. Geol., Vol. XV., No. 5, p. 289, etc.

[3] Ibid., p. 290.

distances both at Scarboro' and along the Don, but by no means always in the sense of thinning out towards the west. For instance, the middle till, the lowest visible at Scarboro', is there generally less than thirty feet thick and for a mile or more scarcely averages five feet in thickness; but at the Dutch Church, where the subglacial débris has been crowded into a deep valley, it reaches a maximum of seventy feet. The same bed of till at the Don brickworks is thirty-five feet thick, and a little farther south, between the Winchester street bridge and Danforth avenue, is apparently ninety feet thick.

The upper till at Scarboro', so far as I have measured it, runs from twenty to thirty feet in thickness; but at Moore Park Station, less than a mile north of Taylor's brickyard it is forty-five feet thick, and at York Mills, three or four miles northwest, is nearly sixty feet in thickness.

In reality the difference in thickness of the drift at Scarboro' and the Don is due rather to the greater or less development of the inter-glacial beds than to the thickness of the till.

If these inter-glacial deposits were formed during slight oscillation of the ice margin, one would suppose that drifting ice floes or even bergs would have been active on the waters of the time, transporting bowlders and other materials, which should be imbedded in the clays and sands of the lake bottom; but neither Dr. Hinde nor the present writer has been able to find stones of any kind in the 140 feet of fossiliferous beds at Scarboro'.

The case of the Alaskan glaciers cited in the article mentioned[1] is in reality not at all analogous to the conditions prevailing at Toronto during the earlier inter-glacial time. In Alaska the Japan current brings comparatively warm moist air right up to latitude 60°; while the highest mountains in North America rise a few miles inland, their icy flanks intercepting the moisture-laden winds from the Pacific and causing a tremendous snowfall in a region where the snowline is only 2000 feet above sea level. If Mt. Fairweather, Mt. St. Elias and Mt. Logan were leveled,

[1] Ibid., p. 278.

how long would the Malaspina and other Alaskan glaciers hold their ground?

At Toronto during one part of this inter-glacial time we had a climate, judging by the flora and fauna, far milder and drier than that of Alaska; and, nothing that can be called a mountain rises between this and Hudson Bay. The inter-glacial time was long enough not only to allow of the deposit of the thick beds of sand and clay that have been described, but to allow the great body of water in which they were formed to be drained to a depth of one hundred and fifty feet, and the new land surface to be deeply eroded. At the Dutch Church, for instance, a valley was dug a mile in width from edge to edge and a quarter of a mile wide at the lowest level exposed by Lake Ontario.[1] All of this must have demanded time and plenty of it. Can any one believe that meantime, while elms and oaks and maples, not to mention the papaw, were growing along the Don, the ice-field, with no lofty slopes to supply gathering ground for névé, was lurking a few miles off, ready to advance and overwhelm the deciduous forests?

It has been pointed out in a previous paper that Toronto lies not more than 500 miles from Hudson Bay or 700 from the center of Labrador, with no mountains intervening.[2] There seems no more reason to assume that a great ice-field existed within those distances while the Don fossils were being buried than there is to assume it at the present day. As a whole, then, the evidence at Toronto seems to support strongly the theory of Geikie, Chamberlin and others as to the distinct ice ages separated by mild inter-glacial times.

The unfossiliferous clays and sands lying between the middle and upper sheets of till and having a thickness of at least one hundred and sixty feet at Scarboro', and of forty at Toronto, indicate a second recession of the ice. The absence of fossils, the presence, though rarely of angular striated pebbles in the clay, and the corrugated and crumpled beds here and there found among the upper sandy layers suggest a cold, perhaps

[1] See Section of Scarboro' Heights.

[2] Am. Geol., Vol. XIII., p. 92.

Arctic climate, implying perhaps only a long recession of the ice, not its complete removal. The upper part, consisting of cross-bedded sand and clayey sand, seems quite widespread, for similar beds lying between the rolling surface of till and a lower sheet of till have been found on a branch of the Don seven miles north of the city, at Pickering twenty miles northeast, and on the lake shore near Newcastle forty miles to the east. It may be that fossils giving a hint as to the climate in this inter-glacial period will be found at some time. The tooth of a mammoth was found last summer on the Don eight miles north of the city at a point where the stream flows over the middle till and cuts away banks showing stratified sand and in some cases the uppe till also, but the fossil may be post-glacial rather than inter-glacia in age. The same holds of two mastodon teeth found several years ago, one on the Don, the other in a sand pit two or three miles east of the city.

If Professor Chamberlin is correct in assigning the fossiliferous beds of Toronto and Scarboro' to the interval between the Iowan and Wisconsin ice ages;[1] then the upper stratified beds imply a still later ice age, separated probably by a shorter and less genial inter-glacial time than the former one. It is however possible, as suggested by Professor Chamberlin, for the beetle-bearing beds of Scarboro' in case they should prove to belong to a lower horizon than the Don beds, that the fossiliferous beds near Toronto are of Aftonian age, *i. e.*, belong between the Kansan and Iowan sheets of till; and that the upper beds represent the interval between the Iowan and Wisconsin ice sheets. The former supposition seems to me the more probable, since there is some likelihood that the mild morainic sheet forming the Davenport ridge and upper Scarboro' Heights runs out in the neighborhood of Toronto, and hence cannot be continuous with the Wisconsin sheet to the southwest. Until the till sheet lying to the north and east of Toronto has its western boundaries traced this point cannot be settled.

A long halt in the retreat of the last glacier, if not a recru-

[1] JOURNAL GEOLOGY, Vol. III., No. 3, p. 273, etc.

descence of glacial conditions after another interval, is indicated by the great morainic loops stretching from Trenton westwards to Lake Huron and passing (as the Oak ridges) about eighteen miles north of Toronto.

The post-glacial history of the region near Toronto has not yet been satisfactorily worked out, though one episode, that of the Iroquois water as described by Dr. Spencer, has left its mark very distinctly in the old beach to the north of the city, and must have had considerable importance as regards the formation of surface deposits.

Much of the somewhat loess-like fine clayey sands of the Humber valley may turn out to be post-glacial; and Dr. Hinde supposes that the upper hundred feet of sand and gravel at the west end of the Scarboro' cliffs are of the same age; but my own observations incline towards an inter-glacial position for these thick and widespread but greatly eroded deposits. Similar sands occurring at York Mills and other points north of the city are undoubtedly covered by the upper till, which may simply have been removed from the more southern parts near the lake. Unprotected by a layer of till these sands are easily attacked by wind and water and superficially rearranged, so that their original structure and relationship becomes obscured.

Of course the Don and Humber with their tributaries have formed in the lower sluggish parts of their courses alluvial deposits of clay and sand that are evidently modern, and in some instances are added to by every spring flood.

The succession of events since Pliocene times in the vicinity of Toronto may now be reviewed in order to bring to a focus the results of the observations described in this paper.

No Pliocene deposits have been found in this region, supposing the earliest advance of the ice to indicate the end of the Pliocene; but the lowest till forms a carpet over the eroded surface of the Hudson River shales. At the time the earliest glacier advanced the Scarboro' region formed a valley whose hollow is now below the surface of Lake Ontario, and there were low hills where the Don and Humber valleys now exist, the

highest observed level of the shale being about eighty feet above the lake at Lambton Mills on the Humber.

The retreat of the ice was followed by a rise in the water of the lake to a level at least 150 feet above the present lake, depositing that depth of clay and sand upon the unweathered till. The Scarboro' water, as it may perhaps be called, was then drained off to a point below the present lake level, and at some points erosion took place to a corresponding depth. It is possible that the climate became warmer during this period of erosion and that the Don beds were deposited afterwards.

At the time of the second glacial period the topography of the region had greatly changed. The Scarboro' Heights already had an elevation of 150 feet, while valleys reaching the present lake level had been cut by Highland Creek and the Don, as well as by the Dutch Church stream, which now has no equivalent. The retreat of the second ice-sheet was followed by a rise of the water to a height of 280 feet above the present lake, the water being cold and lifeless, and bearing ice floes.

Once more the lake was drained, at least partially, and erosion went on, for the upper till is found at a sand pit near the corner of Bloor and Christie streets in Toronto at a level of about 120 feet above the present lake. Either the period of dry land was short, giving no time for the cutting of deep valleys, or the level of the lake of those days was considerably above the present Lake Ontario. The contour of the land at the end of this inter-glacial period is more difficult to settle than in the former one; but it is tolerably certain that the Scarboro' Heights had almost their present height, and that the Don valley was much shallower than at present, if it existed at all.

The retreat of the third ice-sheet was followed as before by a rise of water, Lake Iroquois reaching 160 feet above the present lake to the north of Toronto, and about 190 at Scarboro'. After the draining of Lake Iroquois it is probable that the surface of the country presented much the same rolling swells of till as are now found north and east of Toronto; for, in general, erosion has gone on to a moderate degree only, except where the more

powerful streams have cut out picturesque ravines, such as are seen along the Don and Humber.

It is probable that at the end of the first inter-glacial period the topography had almost as old an aspect as at present, indicating as long a time for erosion as has elapsed since the last ice age; but the dry land stage during the second inter-glacial period was apparently much shorter. The length of time during which high water lasted during the two mild periods must have been very great to allow the immense sedimentary beds to be deposited at Scarboro' and elsewhere, 150 feet thick in the earlier period and 160 in the later. The Iroquois high water stage after the last ice age was probably much shorter, since it has left much smaller sedimentary deposits.

It is a notable fact that each ice-sheet advanced apparently during a time of low water, and was followed by a stage of high water; whether this is to be accounted for by assuming an ice dam at the foot of the predecessors of Lake Ontario, or a change in the level of the land surface caused by the loading and unloading of its ice burden, it is very unlikely that the sea has extended inland so far as Toronto since glacial times. The numerous marine animals found as fossils lower down on the St. Lawrence and Ottawa would hardly have stopped short without reaching the Iroquois bay, if that had been a body of salt water, in communication with the Gulf of St. Lawrence.[1] However, no fresh water forms have been found on its beach, so that the evidence is only negative.

The Scarboro' beds give very instructive evidence as to the comparatively slight erosive power of glaciers. Except near the east end of the section, where, as suggested to me some time ago by Mr. J. B. Tyrrell, the ice front began to rise upon the higher ground during the second advance and crumpled and contorted the clay beds, there is no very striking disturbance even of the stratified sand, though here and there portions of the sand

[1] Two marine shells have been picked up on the Iroquois beach, but, as suggested by Dr. Dall, to whom they were submitted, they have almost certainly reached that position by human agency.

are tilted out of place. The upper layer of till rests in some places on crumpled beds of sand, but more often one sees little trace of disturbance. One might almost describe the till as a lubricant allowing the ice-sheet to glide easily over the inequalities of the surface.

A. P. COLEMAN.

ORIGIN OF CERTAIN FEATURES OF COAL BASINS.

WHILE the general theory of the formation of coal has long been worked out and accepted, it cannot be said that the details of the process are as yet altogether understood. Numerous puzzling phenomena are constantly encountered in all coal regions. In some regards Iowa is a particularly good field in which to work out certain of these points. The coal seams here are relatively thin and lie near the surface. The region has not been disturbed by mountain-making forces. The seams, with one or two exceptions, are not of great areal extent as is common in certain other fields, but are usually quite limited. Indeed it is frequently possible to find the whole of a seam in a single exposure and to be able to trace it readily from one limit to another. Thus the coal beds are reduced to the lowest terms and so become miniature representations of larger coal basins. They serve as models and present opportunities for investigation of certain phases of their structure which in larger basins have been obscured.

In the following paper an attempt is made to explain a few of the different questions which arise in the study of coal beds. The observations were made on the beds of the Iowa-Missouri field alone, and the explanation is only offered as true of certain of these beds. Whether it is of value in other fields or not cannot be told; to workers elsewhere it may perhaps be of suggestive interest.

There is probably no peculiarity of the coal seams of this region which is more constant than what has been called their basin character. In any individual bed the coal is not everywhere of the same thickness; neither does it all lie at the same level. These two variations have usually a constant relation to each other, it being commonly true that the thinner coal is found at the higher points in the seam and the thicker lies in the lower

intermediate regions. The exceptions to this rule are rare and are usually found either where the rise is slight and covers a small area or where the coal is of an impure or bony character. In all the greater differences the coal thins towards the rise.

These lower lying portions of the coal beds are usually called by the miners "swamp coal" or "basin coal" and it is in these swamps or basins that the thicker and more productive portion of the beds lie. In many cases these basins have been traced considerable distances, maintaining the general character of a trough with coal thick at the center and thinning on each side. The area they cover is usually quite irregular. In a few cases the bed underlies a broad circular area thinning quite regularly as it rises in all directions from the center. More usually the length in one direction is much the greater, instances being known where areas of workable coal only about 100 yards wide have been traced nearly a mile. They do not run in direct lines but curve often in an intricate and irregular manner. They are not confined to any one locality but are found in such widely scattered regions as Scott, Keokuk, Jasper, Marion and Lucas counties. Indeed they are present in nearly every region in the state in which coal is mined and are largely sought for by operators. They seem to be more abundant and more irregular in character in the lower horizons. The general character of such a coal basin is represented in Fig. 1, a composite section. On the one side the coal rises twenty feet in a distance of 320, thinning from six to four feet. On the other hand it rises sixty feet in 400 and thins from six to two feet. These two instances are taken from a large number which might be given. The rise of sixty feet is rather unusual, the variation being more frequently from twenty to forty feet. In mining, neither the total variation in elevation nor in the thickness of the seam is usually learned, since so soon as the coal becomes too thin for profitable mining it is rarely traced farther.

A number of these cases have been examined and the relations between the amount of rise and the decrease in thickness determined. The cases examined yield a series of ratios varying

from 1:6 to 1:30. The greater number fall between 1:10 and 1:16, so that the average may be taken as lying between these figures.

In connection with these basins usually a considerable number of small slips or true faults are found. These rarely have a great throw though in a number of instances they parallel each other, forming a step fault with an aggregate throw of considerable extent.

Frequently these slips parallel the basins. In some cases cracks or veins filled with calcite also run in a parallel direction. Another peculiarity often observed is that the slips do not run

FIG. 1.

clear through the coal; more usually they come in from the top but disappear before reaching the bottom. This, however, is not confined to the most pronounced basins, but it is also frequently found in those coals which have a true bedded character, such as the Mystic coal.

In discussing the origin of these basins it will be convenient to consider separately the lines now formed by the top and the bottom of the coal. Considering first the latter the resemblance to the cross section of a valley is at once seen to be striking. This is well brought out in the figure of the Vanderberg mine, a small slope about three miles south of Pella on the Des Moines River. Fig. 2 represents the conditions at this point. The Saint Louis limestone here forms an almost continuous outcrop some distance along the river. It rises to a height of thirty or forty feet. At the place in question the coal lies undisturbed at a level at least fifteen feet below two contiguous limestone outcrops only a few feet distant. It is evident that this coal was formed in a depression in the limestone, and the relations exhibited on the ground show just as clearly that this was a basin of erosion. There is no evidence of disturbance or faulting. The

limestone ledges of the two opposite sides of the basin may be as directly correlated as those on opposite sides of a modern stream. In working the coal in this mine, which is merely a small country bank, it has been found that the coal dips toward the present river. Thus it seems that this vein was laid down in a small gully or ravine opening out into some larger basin, the margin of which was located approximately along the present course of the Des Moines.

In these and other cases it is at once seen that the lower line

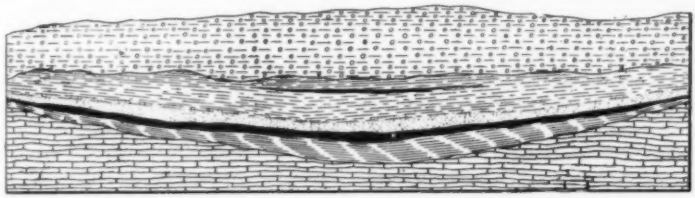


FIG. 2.

is the cross section of a previously existing ravine. There is no reason to doubt that a similar statement would hold in a great number of the remaining cases. In all places where there has been an opportunity to examine the underlying rocks this has been found to be true. In a majority of the other cases known the coal horizon lies undoubtedly above an unconformity of erosion, and the underlying rocks are known to have suffered erosion sufficient to account for just such outlines. Not all, however, are known to be so located. In a few instances similar basins are found in seams which so far as known do not overly any unconformity. In the veins which lie high up in the coal measures the coal often has a rolling or undulatory character, differences of twenty to twenty-five feet in elevation being not uncommon. In such cases there is not always a constant rule as to the thinning of the coal over the higher points. It is only as the basins are traced out to their limits that the rule appears to hold. These minor changes can readily be accounted for by the secondary changes induced by the consolidation of the

immediately underlying strata. In other instances, as for example the "second seam" in the Eureka mine at Des Moines, the usual rule holds true.

If we conceive the coal seam at the time of its formation, we would have essentially what may be seen in any modern peat swamp. The loose vegetal matter lies under the water completely covering the irregularities of the bottom and rising to a practically uniform level a short distance below the surface of the water. In the process of change by which the vegetal matter is transformed to coal it loses a considerable percentage of gas and water so that the relative percentage of carbon increases in regular order from wood to anthracite.

Bischof in studying these changes calculated the total loss which takes place in the change of wood into coal. He assumed that the change had taken place by three processes:

1. By the separation of carbonic acid and carburetted hydrogen.
2. By the separation of carbonic acid from the elements of wood, and by oxidation of hydrogen by external oxygen.
3. By the separation of carbonic acid and water from among the elements of wood.

Under these three assumptions the wood lost as follows: (1) 78 per cent.; (2) 58.3 per cent.; (3) 45.5 per cent.

It is readily seen that with so great a loss of material there must be a corresponding decrease in volume. As the gases escaped, a process yet in operation in the deeper mines of other regions, the strata settled. The amount of this settling may be arrived at as follows.

In the coal basin figured above it will be seen that at one point the floor of the coal bed is sixty feet above the lower portion adjoining. At the time of the deposition of the vegetal matter both these points were covered to a considerable depth, the loosely compacted material rising probably to an even level. It is evident that at that time there was sixty feet of material less over the high than the low point. The whole mass became so deeply buried that the pressure of the overlying beds may be

assumed to have been equal at both points. This assumption is especially safe since the two points are but a short distance apart. As the matter yielded to this pressure, it decreased in bulk until in the end it assumed the thickness now seen. The fact that the character of the coal at both points is similar confirms the assumption that the conditions and pressure at both points have been the same. It thus becomes evident that the original difference of sixty feet in the thickness of the vegetal matter ultimately gives a difference of four feet in the thickness of the coal; or that each foot of coal now present occupies one-fifteenth the vertical space which it originally filled. This ratio has been calculated for a number of cases in Iowa and is found in a major portion of instances to lie between one to ten and one to fifteen. Thus the rule is reached that in the process of consolidation Iowa coal seems to have been reduced to from one-tenth to one-fifteenth its original bulk. It should be remembered in comparing these estimates with those made in other fields that the Iowa coals have not been subjected to the action of mountain-making forces. There has been no lateral pressure, and the vertical pressure has probably been comparatively slight.

The changes due to this compression would be slight in the beds under the coal. To the degree in which they were soft and unconsolidated they would themselves be amenable to the same pressure. As a matter of fact they were only slightly affected. The fire clay immediately under the coal, if thick, frequently shows the greatest changes. It was of course subject to irregularities of deposition and hence varies in thickness. When the strata consolidated the fire clay was more unyielding than the coal so that a greater thickness of fire clay is marked by a "horseback" or ridge pushed into the coal. Changes in the thickness of the coal bed would not greatly affect the underlying strata except to the slight degree in which they may at times have lessened the pressure on the fire clay. The effect of such a decrease would correspond to that now seen in "creeps" which are due to a similar cause.

In the coal bed itself the effects of the settling may be seen

in the small slips or faults which are encountered. As the coal became older and less plastic it was able to resist the pressure for a considerable time. Finally the accumulated force would cause it to yield, and this yielding would take the form of a series of slips or of cracks along its edges rather than of a gradual unbroken deflection. Since the lower beds were more largely resistant the faults do not often extend far into them and frequently do not even extend to the bottom of the coal.

In the beds above the coal the effects of this action must be large. The shales which lie immediately over a coal seam are frequently quite badly faulted. This is usually more evident in bituminous than in argillaceous shale. This is probable due to the fact that just in proportion to the degree with which they are charged with bituminous matter they would themselves undergo the same loss and other changes which occurred in the coal. In general, however, shale accommodates itself readily to pressure. Limestones and sandstones prove more unyielding and break with sharp fault lines into the underlying coal beds.

One of the most important results of these changes and the one which gives them their deepest economic significance is the part which such a change in a coal seam would play in inducing the deposition of overlying seams. Starting with the conception of a coal swamp as a low-lying coastal marsh it will be seen that any irregularity in the surface which makes an inreaching basin will afford better opportunities for the formation of a coal seam since it will give a better—more protected—area for the growth of plant life and will shield the deposit from the incursion of currents. The influence of such preëxisting irregularities is believed to be seen in the coal seams already described, as for instance that at the Vanderberg mine. Now if there be a sufficient cause for the prolonged and gradual subsidence of the area, the ideal conditions for the formation of a coal seam would be present. It must be evident that in the course of such secondary changes in a coal body as has been sketched above there would be, unless sedimentation were active, an area over each coal basin which would become depressed. For a considerable

time this area would continue to sink. This action would be very slow and probably long continued. As a rule the strata covering coal seams are shales and are indicative of slow and even deposition. If then a coal basin be formed and coal be deposited in it, that coal in the process of solidification would, provided the general subsidence of the region continued, thus give rise to conditions favorable to formation of a second seam above it. This second or upper seam would repeat to a greater or less extent the irregularities of the first. The inequalities in the thickness of the upper seam would probably not be so great as in the lower seam.

From the above it follows that if in working a coal seam — where the general conditions are the same as in the Iowa field — a marked basin character is found, it is indicative probably of one of two things. Either the coal lies above an unconformity and the irregular character of the coal is the expression of that fact, or it may lie above another coal seam and its irregular distribution may have been conditioned by the equal settling of the lower bed.

How far this may aid in prospecting for coal seams cannot now be said. It must not be forgotten in applying it that there are many beds other than coal which undergo important secondary modifications in thickness. The influence of underground waters in washing out underlying strata and thus producing irregularities in the position of overlying beds may also perhaps need to be taken into account. In at least one instance, however, there is confirmation of the reality of the process sketched above.

In the region around Des Moines there are a number of mines which have at different times worked two seams of coal separated by thirty-five to forty feet of shale. The maps of these mines have usually been very imperfectly kept and levels are only occasionally available. In the Eureka mine the second seam is now being worked. The first is a thin seam which has no value. The third lies about forty feet below the second and has been worked out. In both the second and third seams the

basin character is a prominent feature. *It is found in working the second seam that the thicker low-lying coal overlies the areas from which the swamp coal was taken in the third seam.*

The opportunities for thus testing the truth of this theory are, in this field, quite rare since only a very small number of the mines ever work more than one seam.

H. FOSTER BAIN.

IOWA GEOLOGICAL SURVEY,
May 25, 1895.

PREGLACIAL GRAVELS ON THE QUARTZITE RANGE NEAR BARABOO, WIS.

WITH SUGGESTIONS AS TO THEIR CORRELATION.

At a number of points on the east bluff of Devil's Lake, and about half a mile from it, at an elevation of 1560 to 1580 feet, A. T., there are traces of gravel differing radically from any other surface formation known in this part of the State. These traces are, in general, very meager, consisting of scattering pebbles only. They may be seen along the crest of the south face of the east bluff for a distance of 80 rods or more, and along the path leading down from the summit of the bluff, in the vicinity of the Devil's Doorway. This path leads over the talus slope of the quartzite range, and the well-rounded pebbles of chert, flint and light-colored quartz are in striking contrast with the purple quartzite blocks over and among which the pathway leads. The pebbles along the path are clearly in secondary positions, having come down from the crest above.

There is a single point, a few rods north of the upper end of he path referred to, where the same sort of gravel may be seen to exist in considerable quantity. The crest of the ridge is here somewhat broad and flat. On its surface a well was dug some years since, and at the site of the excavation, the gravel was found to have a depth of 16 feet, and to rest directly upon the firm surface of the quartzite.

The gravel thrown out in the digging referred to has been subjected to the weathering of many years, but its character does not appear to have been perceptibly modified. It is made up wholly of quartzose material, consisting principally of chert, flint, vein-quartz, and silicified fossils. A glance suffices to show that the larger part of it was derived from limestone formations. In size, the constituents of the gravel range from tiny pebbles to cobbles, three, four, and even five inches in diameter. The

pebbles, especially the smaller ones, are for the most part thoroughly well rounded, though there are occasional conspicuous exceptions. For example, a silicified fossil, such as a fragment of an orthoceras, is now and then found, the form of which is almost perfectly preserved, showing that rounding was not in all cases carried to an extreme degree. Many of the larger pebbles or cobbles are less completely smoothed than the smaller ones, but even these are rarely angular. All, or essentially all, show distinct evidence of having been subjected to very considerable wear. On the whole, the constituents of the gravel are as thoroughly rounded and worn as the constituents of any gravel of similar materials which the writer has ever seen.

Another characteristic of the gravel is the extreme smoothness of its pebbles. While the subangular forms are still retained in some cases, the surfaces even of the subangular pebbles are almost uniformly smooth. Not only this, but many of them, have a sort of gloss or polish which is very unusual, and which could only be acquired by pebbles of extreme hardness.

Among the silicified fossils which enter into the gravel as constituent pebbles, there were found representatives of the following groups: orthoceratites, gastropods, brachiopods, crinoids, bryozoa and corals. The following forms are recognizable:[1] *Astrocerium venustum* Hall, *Favosites niagarensis* Hall, *Fenestella* cf. *termiceps* Hall, *Callopora* cf. *elegantula* Hall, *Retepora* sp. indet., *Zaphrentis* cf. *turbinata* Hall, crinoid trochites, gen. indet., *Orthoceras junceum* Hall. Of all the determinable species, five belong to the Niagara of Wisconsin, and one to the Trenton or Galena.

The quartzite surface immediately beneath the bed of gravel was not seen by the writer, but by those who dug the well it is said to be much worn and polished. Its surface also is said to be marked by very notable pot-holes. This statement can readily be believed, since the surface of the quartzite at various points in the vicinity is seen to be so marked. At one point, at the very crest of the south face, a pot-hole was found about

[1] The determinations were kindly made by Dr. E. C. Quereau.

eighteen inches deep, and about eight inches in diameter. When found, this was nearly filled with soil, but on removing the soil and the vegetation which grew in it, there was found at the bottom of the hole a small amount (a pint or so) of gravel, identical with that at the site of the well.

The fact that the surface of the quartzite on which the gravel under discussion rests, is market by pot-holes, suggests that the latter were developed when the former were deposited. The pot-holes have been observed before, and have been ascribed to glacial streams descending from the surface of the ice. But the surface where the observed pot-holes and gravel occur is beyond the reach of the ice of the last glacial epoch, and in this region, the ice of earlier glacial epochs is not known to have reached farther west than that of the last. The drift limit, as well as the ice limit in this region, is of exceptionally clear definition, so that it seems certain that the pot-holes are not *moulins*.

It cannot be supposed that the gravel and the pot-holes are the product of glacial waters operating beyond the edge of the ice, first, because the crest of a high ridge where the gravel and pot-holes are, is not the place where extra-glacial waters would run, and, second, because the gravel itself is radically unlike the glacial gravels of the surrounding country, both in its lithological constitution and in its physical condition. If similar materials enter into the constitution of the glacial drift at all, they do so in very subordinate measure. It is incredible that running water, working upon the glacial drift of the region, could bring out of it chert, silicified fossils, quartz, etc., without the slightest admixture of any of the many other constituents which make up the larger part of the drift of the region. The lithological constitution of the gravel is such as to make it altogether certain that it is not glacial, or aqueo-glacial.

The physical condition of the gravel is hardly less conclusive than its lithological constitution, against its glacial or aqueo-glacial origin. The pebbles are rounded and smoothed to a degree altogether beyond that which characterizes the comparable materials of the stratified drift. When the position, the

relation, the constitution and the condition of the gravel are duly considered, there is no escape from the conclusion that it is preglacial.

This preglacial gravel at this elevation and in these surroundings, is surely a striking fact, although it may not now be possible to define its exact significance. It might be thought to be either, first, a remnant of gravel deposited along the course of a former stream, and therefore very local, or, second, a remnant of a formation which was once widespread. Between these two hypotheses it should be possible to decide, if sufficient data are available. While relevant data are less complete than could be desired, they are sufficient to constitute a strong presumption in favor of the latter hypothesis, although the pot-holes, considered by themselves, might seem to point to the opposite conclusion.

It is well known that high-level gravels have a wide distribution in the Mississippi basin south of the limit reached by the ice of the Pleistocene period. Such gravels are well known at various points in the southern part of Illinois, Indiana and Missouri, in Arkansas, Kentucky, Tennessee and in the states further south. Comparable gravels are widespread in the West. In the South these gravels have sometimes passed under the omnibus name Orange Sand. They have sometimes been regarded as of recent (Pleistocene) age,[1] though in late years they have been regarded more commonly as pre-Pleistocene.[2] It is not to be understood that all the gravels within the general area here referred to are of the same age. Reference is here made especially to the high-level gravels, as distinct from those which occupy the lower lands and the valleys. According to our present interpretation, the gravels which are found capping the hill tops and the high-level plains within the general area specified, represent an older (pre-Pleistocene) formation, while

[1] DANA, Manual of Geology, Fourth Edition, p. 964, and UPHAM, American Naturalist 1894, pp. 979–988.

[2] CHAMBERLIN and the writer; Am. Jour. Sci., Vol. XLI., pp. 359–377; 1891. McGEE; The Lafayette formation, Eleventh Annual Report U. S. G. S. CALL; Arkansas Geological Survey, Annual Report for 1889, Vol. II. SMITH; Report on the Geology of the Coastal Plain of Alabama, 1894.

much of the gravel which occupies the lower lands and the valleys of the same general area, represents a younger formation derived from the older. It is also believed that the valleys and lowlands in which the latter class of gravels are found, were developed by subaërial erosion from the plains on which the high-level gravels occur, after the latter were laid down.

The northward extension of these high-level gravels of the south has never been determined. It has long been known that they reached as far north as Pike and Hancock counties, Illinois.[1]

In August, 1891, a paper was read before the Geological Society of America,[2] in which attention was called to the existence of certain isolated and hitherto unknown beds of high-level gravel, lying farther north than most of those previously known, and believed to be their equivalent At that time the gravel had been found at various points as far north as Adams county, Illinois, where it was found to underlie the glacial drift. Where the new finds of gravel were made, in Calhoun, Pike and Adams counties, the beds occur, as in the earlier known localities, on the crests of high hills or ridges, or on high plateaus, positions which clearly indicate that the formation was deposited long before the surface had assumed its present topography. Since the gravel underlies the glacial drift of this region at but a few points, and these the most elevated, and since its materials do not enter into the constitution of the glacial drift in any large quantity, there is no room to doubt the conclusion that the high-level gravel of western and southwestern Illinois had been largely removed by erosion before the glacial drift was deposited. Since the amount of erosion involved is large, affecting not only the gravel but also the underlying indurated strata, and since the overlying drift belongs to the earlier part of the glacial period, there is little room to doubt that the gravel is preglacial, and, therefore, according to the commonly accepted standard of classification, pre-Pleistocene.

[1] Geol. Surv. of Ill., Vol. I., p. 331, 1866; Vol. IV., p. 37, 1870.

[2] SALISBURY; Bulletin of the Geol. Soc. of Am., Vol. III., p. 183, 1892.

The gravel of Adams county is 175 to 200 miles north of the northernmost point where the high-level gravel has any considerable areal development. Within this distance, however, gravel is known at many points. At all these points its constitution, its physical condition, and its geological and topographical relations are such as to leave little room to doubt that the existing beds are to be correlated with each other, and that they are the erosion remnants of a once continuous formation, which extended over southern Illinois, reaching at least as far north as Adams county.

The study of the high-level gravels of adjacent states had at that time (1891) left no room to doubt their correlation with the similar formations of Illinois. It is confidently believed that the gravels on the crest of Crowley's ridge in Arkansas, and its continuation northward into Missouri, are parts of the same formation which once covered the southern portion of Illinois, and considerable parts of Kentucky and Tennessee. To the south, this formation probably extended to the gulf. Its extreme eastward and westward borders, as originally developed, have not been determined, but in both directions the extension was great. In Indiana it is known to have reached as far east as Perry[1] county. The possibility should be recognized that these high-level gravels may not all belong to one formation, although the remnants thus far referred to in Indiana, Illinois, Missouri and Arkansas are so similar in constitution and in all their relationships as to raise a presumption in favor of this view.

At the time of the reading of the paper cited above, the gravel had not been found at any place north of Adams county, Illinois. In spite of this fact, it was believed that the formation once extended further north since its materials, so it was thought, were to be recognized as minor constituents of the glacial drift at various points as far north as Rock Island county. If this identification be correct, it means that at the time of the deposition of the drift in Rock Island county, remnants of this preglacial gravel formation were still in existence as far north as that point. The localities in this county where material

[1] Bull. Geol. Soc., Vol. III., 1892, p. 186.

derived from the pre-Pleistocene chert gravel were thought to enter as constituents into the drift, are 100 to 125 miles north of the northernmost point in Adams county, where the formation is known to occur *in situ*. At many intermediate points, similar materials were found in the glacial drift. Quantitatively they are unimportant, and their absence is more common than their presence. Their occurrence and distribution in the drift are such as would have resulted had erosion remnants of the high-level gravel existed when the ice invaded western Illinois.

In the paper referred to it was stated that certain limited beds and scattered remnants of hitherto unexplained quartzose gravel were known to exist within the driftless area of Wisconsin, and the suggestion was hazarded that these gravel remnants were very likely to be correlated with the gravels further south. The remnants of gravel in Wisconsin occur at various points from Crawford county on the south, to Dunn county on the north. Wherever known, these remnants occur on the crests of ridges and the summits of isolated hills. Not only this, but they are found on the summits of the highest elevations of the region within which they occur. They often consist of nothing more than scattering pebbles, though beds a few feet in thickness are known, the most considerable being near the village of Seneca in Crawford county. The gravel is here composed almost wholly of quartz.[1] As at various points further south, the gravel is here cemented by iron oxide into a firm conglomerate. The average depth does not appear to be more than five or six feet, but it has been penetrated to very much greater depths at one or two points. The exceptional depths are thought to represent the fillings of fissures, which affect the underlying rock.

Had gravel remnants similar to those of the driftless area existed in western Illinois at the time this region was glaciated, they would have contributed to the drift of their respective localities, just such material as it has been observed to contain. They would have made considerable contributions where they were considerable, and meager contributions where they were

[1] STRONG, Geology of Wisconsin, Vol. IV., p. 88.

meager. The facts, (1) that the pre-Pleistocene gravel exists in the form of widely separated erosion remnants south of the drift-covered country; (2) that isolated remnants of it are known to exist at several points beneath the drift, as many as 125 miles north of the southern limit of glaciation (Adams and Hancock counties); (3) that the glacial drift here and there at various points for 90 miles further north (Rock Island county) contains gravel which might well have come from remnants of the northern extension of the same formation; (4) that remnants of similar gravel occur in the driftless area, where there has been no chance of destruction or burial by the ice; and (5) that the gravel in all these situations has the same topographical habit, all point to the conclusion that they are parts of a once widespread and continuous gravel formation.

The gravel on the east bluff of the Devil's Lake is about 60 miles east of the gravel of Crawford county. It is about 150 miles northeast of that part of Rock Island county where similar gravel is a local constituent of the glacial drift. The topographic situation of the gravel is the same as that of all the widely distributed remnants further west and south, to which reference has already been made. In its constitution and other physical characteristics, the Devil's Lake bluff gravel is so similar to that of the region farther south (Adams county, Illinois, etc.), that it could hardly fail to recall the southern formation to one who had seen it in southern Illinois, Missouri and Arkansas. The geographic and topographic position of the Devil's Lake gravel, as well as its constitution and physical condition, make it altogether rational to infer that it may have been connected with the isolated beds of similar material already referred to, and that, as originally developed, the formation of which the existing beds are but remnants, had a much greater extension than has heretofore been recognized. If the gravel on the bluff east of Devil's Lake be a remnant of an extensive preglacial gravel formation, it becomes a matter of much importance to fix its age.

Limited occurrences of somewhat similar gravel or ferruginous conglomerate are known in southeastern Minnesota, and

have been referred, with some doubt, to the Cretaceous.[1] On the other hand, its relations are so uncertain as to have led to the suggestion that it may represent a remnant of the Oriskany sandstone.[2] It is clear that if its relations to the underlying strata do not preclude its reference either to the Oriskany or to the Cretaceous, they do not preclude its reference to the Tertiary. Since it is overlain by glacial drift only, it would not seem that there is anything in its relations to superior strata to preclude its reference to the Oriskany, the Cretaceous, or the Tertiary. Similar gravel in Fillmore county is unhesitatingly referred to the Cretaceous,[3] because of its association with certain clays containing Cretaceous fossils.

The topographic relations of the gravel and conglomerate of Minnesota here referred to, are the same as those of similar deposits in the driftless area of Wisconsin, and the suggestion is here renewed that they probably go together, and that they are very likely to be correlated with the high-level gravels further south.

Conglomerate which may be found to belong with the gravel and conglomerate of Minnesota, Wisconsin, Illinois, and regions further south, is known to exist at Rockville, Iowa. This was referred to by McGee[4] in 1879, as belonging to the glacial series.

In the Devil's Lake gravel there is nothing, so far as known, to fix its age. It rests unconformably on Algonkian rock, and it is evidently preglacial. It contains silicified fossils, which seem to have been derived chiefly from the Niagara limestone. Internal evidence, therefore, does not prohibit the reference of the gravel to any period between the Niagara and the Pleistocene. If this gravel is to be correlated with the gravels of southern Illinois, it is doubtless late Tertiary. On the other hand, there is no inherent evidence which precludes its reference to the Cre-

[1] Final Report Geol. and Nat. Hist. Surv. of Minn., Vol. I., pp. 305–309.

[2] Loc. cit., pp. 355–6.

[3] Loc. cit., pp. 307–11.

[4] Geological Magazine, Vol. VI, 1879, p. 360–1.

taceous,—the reference which Professor Winchell has suggested for the high-level preglacial gravels of southern Minnesota. Assuming that the Minnesota gravel referred to is Cretaceous, and comparing the Devil's Lake gravel with that of Minnesota alone, this would perhaps seem to be the most natural reference of the Wisconsin beds.

It is not beyond the range of possibility that some of the gravel beds here mentioned are Cretaceous, while others are Tertiary. The gravel beds of Minnesota and Crawford county, Wisconsin, resemble each other much more closely than either resembles the Devil's Lake bluff gravel. The Devil's Lake gravel, on the other hand, is strikingly like that of the areas further south, and on the ground of physical likeness would be classed with it, rather than with the beds of Crawford county, Wisconsin, and of southeastern Minnesota. It is distinctly recognized, however, that physical likeness is not a safe criterion from which to draw important conclusions. Both in Crawford county and at Devil's Lake, the gravel is unaccompanied by the clay and sand beds which are present in Minnesota, and on the basis of which the Cretaceous correlation was suggested. At various points in western and southern Illinois, on the other hand, clay exists immediately beneath the gravel; the same is true in some parts of Missouri. So far as known, no determination of the age of the clay of these regions has been made, nor is it known that the clay and the overlying gravel belong to the same period. So far as association with clay is concerned, the gravel of southeastern Minnesota would seem to belong with the gravel of western Illinois (Pike and Adams counties). Manifestly little weight can be attached to this association, on the basis of present knowledge.

There is some reason for believing that there may be both late Tertiary, and older (possibly Cretaceous) gravel formations south of the Ohio River. The gravel between the Cumberland and the Tennessee Rivers, exposed in the deep railway cut, may represent a formation much older than the gravel of Adams county, Illinois, or of Crowley's ridge, Arkansas. It is not to be

looked upon as impossible, therefore, that both Cretaceous and Tertiary gravels may have extended as far north as Wisconsin. If so, it is possible that remnants of both still exist, though until we have positive evidence of two formations, the presumption is in favor of but one.

Whatever the age of the Devil's Lake gravel, its topographic position is full of significance. It occurs on one of the highest points of the state. Within the driftless area, where such gravel as this might have escaped destruction if it ever existed, there is, we believe, but one other point so high as that on which the gravel occurs. This is the Blue Mounds. On the crests of these mounds, corresponding gravel is not known to occur, though they have never been examined, so far as known, with this point in view.

It is clear that the gravel could not have been deposited in its present position, since the existing topography was developed. The ridge on which it occurs is about 700 feet higher than the Barbaoo River to the north, and about 800 feet higher than the Wisconsin River to the south, and, what is still more significant, it is 500 or 600 feet above the general level of the extensive drift-covered sandstone plain which surrounded it. Since the gravel is not glacial, there is but one interpretation possible concerning the topographic conditions and relations at the time it was deposited. At that time the surface on which it occurs was not higher than its surroundings. This fixes the age of the gravel in terms of erosion. It was deposited before the quartzite ridge was isolated, that is while the Potsdam and later formations still reached the top of the harder quartzite.

The amount of erosion which has been accomplished since the gravel was deposited is, therefore, very great. It should be noted that this erosion is not measured simply by the excavation of valleys on either hand to the depth of 700 and 800 feet respectively. Since the gravel was deposited, the general surface of the surrounding country has been cut down to the extent of 500 to 700 feet, disregarding the heavy drift deposits which have helped to build it up again. This building up process was con-

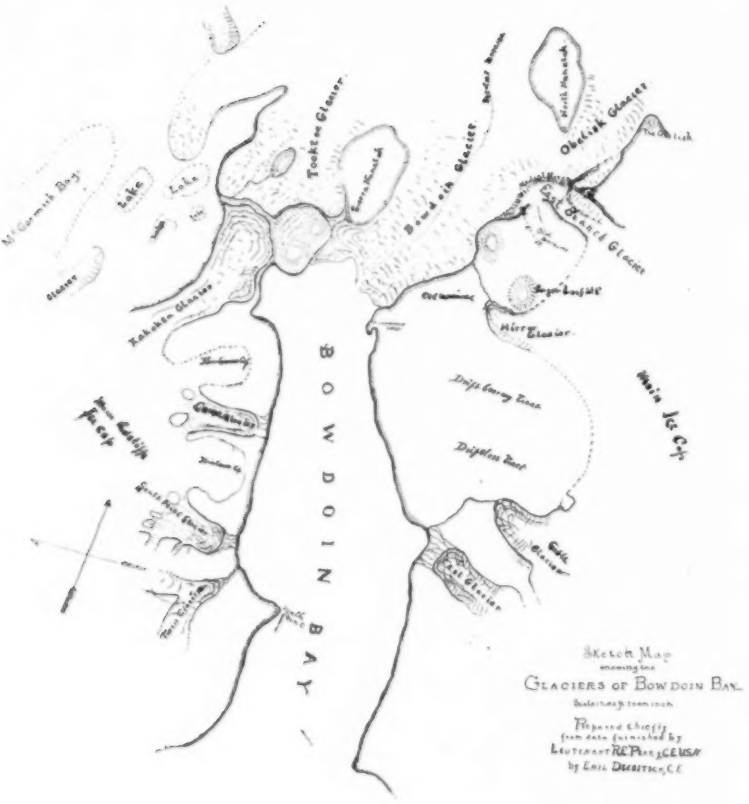
siderable, for there can be no question but that in this region glacial deposition greatly exceeded glacial erosion. The quartzite range is not simply an inter-stream ridge; it is an elongate monadnock standing up out of a very extensive peneplain. The amount of erosion necessary to isolate it was much greater, and demanded a very much longer period of time than would have been necessary simply to cut valleys 700 or 800 feet deep. Looked at from this standpoint, one is inclined to think that the age of the gravel may be as great as Cretaceous. On the other hand the total amount of erosion which has taken place in the upper Mississippi basin since the deposition of the gravel is but a fraction of that which is believed to have taken place in some parts of the west in late Tertiary and post-Tertiary time.

Although the topographic relations of the gravel do not enable us to fix its age in the accepted terms of geological chronology, they seem to bring out the general fact that the present physical features of the upper Mississippi basin are of later origin than has been generally supposed. This is especially true if the gravel shall prove to be Tertiary, and the balance of evidence seems at present to favor this interpretation.

There is still another direction in which the gravel bed at Devil's Lake is of interest. The fossil content of the gravel, as well as the greater quantity of chert, indicates that it was derived in considerable part from the Niagara limestone. It has long been believed that the Niagara limestone of Wisconsin, now confined principally to the eastern margin of the state, once extended much farther west, over regions whence it has been removed. The constitution of the gravel affords an interesting confirmation of this belief, and seems to indicate that the Niagara may have had even a greater extent than has been supposed, for it can hardly be doubted that, when the gravel was formed, the limestone either overlay the quartzite, or existed at some equally high point in the immediate vicinity. Not only this, but the presence of one fossil, *orthoceras junceum*, which, so far as known, can be referred only to the Trenton or Galena, suggests that one or both of these formations also once passed over the quartzite

ridge, or at least that they were once at equally high points in the immediate vicinity. If these formations once covered the quartzite and were overlain by the Hudson River shale, the Niagara limestone, which, in Wisconsin, immediately succeeds the Hudson River shale, must have originally lain very high above the crest of the quartzite range. If the Trenton lay upon the quartzite directly, and if it and the succeeding Galena and Hudson River formations had their usual thickness, the base of the Niagara could hardly have been less than 500 feet above the the top of the east bluff at Devil's Lake. If the St. Peters sandstone and the lower Magnesian limestone overlay the quartzite beneath the Trenton, the base of the Niagara must have been still higher.

R. D. SALISBURY.



Sketch Map showing the Glaciers of Bowdoin Bay.

GLACIAL STUDIES IN GREENLAND. VII.

THE REDCLIFF PENINSULA.—*Continued.*

Glaciers on the East Side of Redcliff Peninsula.—The Fan and Bryant glaciers that have been previously described represent the group of ice tongues which protrude from the *mer de glace* of Redcliff peninsula on the south. A group of similar tongues push out toward Bowdoin Bay on the east, and two of these will now be described, the South Point glacier and the Gnome glacier. The general aspect of the east side of Redcliff peninsula is shown by the accompanying photographic illustrations. Together the two illustrations form a panoramic view. The point of observation is the border of the main ice-cap on the east side of Bowdoin Bay. The foreground is the edge of the plateau on which the main ice-cap lies. The depression that traverses the middle of the view is the valley occupied by Bowdoin Bay. The flat snow field beyond and the nearly level sky line show how truly the peninsula is a plateau and how far the glacial phenomena are different in general aspect from the Alpine type. At the extreme south lies the Twin glacier. Just north of it, but scarcely shown in the view, is the South Point glacier. At the left of the lower view lies the Gnome glacer. At the right hand of the lower figure the plateau may be seen to fall away to the low neck that connects it with the mainland. The geographic relations of these features may be seen by reference to the accompanying map of Bowdoin Bay and vicinity.

South Point Glacier.—This is a lobe of the peninsular ice-cap occupying a short valley notched in the edge of the plateau. Its width was estimated at one mile and its length at two. It descends from the plateau rather abruptly, as is the fashion of the valleys of the region. The ice as it makes its descent to the valley is interrupted by three islands around which it flows and from which it carries away medial moraines. These moraines,

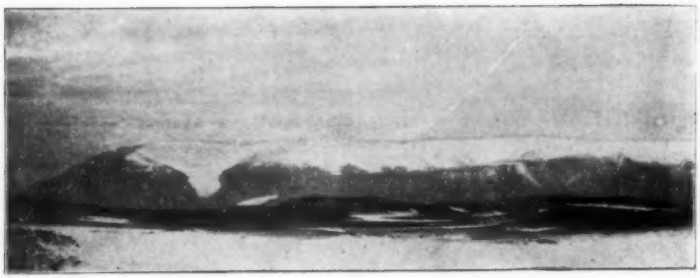


FIG. 43. General view of the south portion of the Redcliff peninsula, showing its snow-cap and the location of Twin and South Point glaciers. The point of view is the edge of the main ice-cap east of Bowdoin Bay, and the direction of view southwest. The immediate foreground is the wind-drift border of the main ice-cap which had been freshened and extended by a recent snow-fall. The main foreground is the edge of the plateau which extends backwards under the main ice-cap. The depression in the middle of the view is the valley occupied by Bowdoin Bay. Beyond lies the Redcliff peninsula. The Twin glacier occupies the valley at the left. The South Point glacier occupies a valley that begins a little to the right of the center of the view and extends towards the left, emerging at a point a little to the right of the Twin glacier where a small part of the glacier is seen. The horizontality of the summit plane is worthy of special note.

FIG. 44. General view of the north portion of the Redcliff peninsula, showing its snow-cap and the location of the Gnome glacier. Point of view the same as in Fig. 43, of which it is the complement. At the right the surface descends abruptly to the low ground that connects the peninsula with the mainland.

however, curve outwards to the sides of the valley before they reach the end of the glacier. At least one lateral glacier joins the main one on the south, bringing in an additional moraine, but this is also carried to the side of the glacier before advancing far down the valley. On the south side also there is an interesting "hanging" glacier descending very steeply from the summit of the plateau. This may be seen in Fig. 45. This

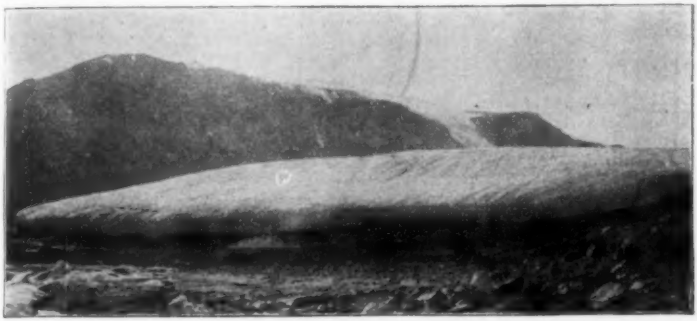


FIG. 45. View of the extremity of South Point glacier from a point on the north side of the valley looking southwesterly. The point of the glacier at the left is near the center of the valley, and a face similar to that turned toward the observer is presented beyond this point looking southeast. The dark band at the bottom is the talus slope and the bowldery layer of the glacier. The rather sudden change in the upper surface slope of the glacier is probably due to a terrace of rock extending across the valley and appearing at the edge of the glacier at the right. By a little care it will be seen that the bedding lines on the face of the glacier are continuous with those on the upper surface. The little steeply-descending glacier on the face of the snow-capped plateau in the background is the "hanging" glacier referred to in the text.

little glacier, however, is wasted and stayed at the foot of the steep slope before it is able to join the larger glacier. The measurements of its slope indicate that it reaches an inclination of twenty to thirty degrees in its steeper parts, but, singularly enough, it was not greatly crevassed, not even where it bent over the brow of the plateau.

South Point glacier stops short of Bowdoin Bay by perhaps half a mile. The interval is occupied by gravelly and bowldery

wash forming a sloping plain. On this the end of the glacier rests, except at the north edge, where it descends a rock terrace. There is a notable dropping down of the upper surface not far back from the end of the glacier, and this stretches well across

FIG. 46. Portion of the front wall of South Point glacier near the center of valley, seen looking southwesterly. The upper portion is nearly pure ice, but shows the stratification well. The dark ice at the upper edge of the talus slope is the bowldery layer mentioned in the text. The material of the talus is chiefly derived from this. The blocks of ice on and at the foot of the talus slope are masses detached from the glacier.

the valley, as seen in Fig. 45. It suggests that this rock terrace extends far out under the ice in the bottom of the valley. Owing to this or some other cause the glacier's upper profile is less symmetrical than those of the Bryant and Fan glaciers.

The most interesting feature of the glacier is its frontal edge. The view shown in Fig. 45 partially illustrates its character. It was taken from the northeast, looking obliquely across the axis

of the glacier. A view from the southeast would show a very similar face and the two combined would make up the extended terminal curve of the ice lobe. Fig. 46 is a nearer view in the middle of the valley, and Fig. 47 is a still nearer one on the

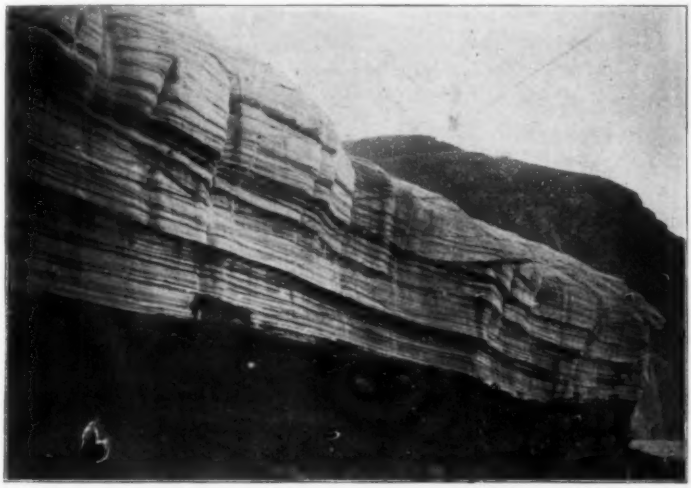


FIG. 47. Portion of front wall of South Point glacier near center of valley, seen looking northwesterly. The dark shading brings out prominently the stratification of the upper part, which is obscure in most of the views presented, because of the light color of all parts. The dark layer at the base and the talus slope are continuous with those of the preceding figure.

southeast face, looking in the reversed or northerly direction. These views, particularly Fig. 47, show the pronounced stratification of the glacier, the presence of débris between the layers, the development of a vertical and even overhanging face, and the formation of a notable talus slope in front. The stratification is much the same as that of the Bryant glacier, but more regular and pronounced in the upper portion where the débris is slight. It is worthy of note that these lines of stratification appear upon the upper surface also and may be traced consecutively

from this surface to the vertical face, as illustrated in Fig. 45. The lines which represent the outcropping of the layers on the surface form sweeping curves more or less concentric with the frontal edge of the glacier. By differential melting of these layers little steps or terraces are formed, which sometimes become somewhat pronounced. This phenomenon was observed on other glaciers.

As in the preceding glaciers—indeed in all the glaciers of Greenland that were seen—the upper part was found essentially free from débris, while the basal part was well inset with rock rubbish of various kinds. Along almost the whole face there was a layer twelve or fifteen feet thick at the upper edge of the talus slope that was so thickly inset as to be almost black with débris (Fig. 46). A part of this blackness, however, is attributable to the illusive effects of the surface wash. Much of the débris of this layer was coarse. Large bowlders were abundant, but all grades were present down to fine clay. When freed by melting it constituted a very coarse, stony till. Many of the fragments were rubbed, bruised, scratched or polished in typical glacial fashion. The assemblage of rock species was unusually interesting, embracing gneissic and igneous rocks and the gray and red sandstones. The walls of the valley and doubtless its bed were formed of the gneissic series into which had been intruded igneous dikes. Among these were some of a markedly green rock of diabasic aspect that was capable of receiving and exhibiting glacial markings with unusual facility. The sandstone series capped the plateau and formed the nunatakes at the head of the valley in the main. The distribution of the formations seemed to favor the view that the débris of the very bowldery layer above described was introduced at the cataract at the head of the valley.

The melting out of the débris of this bowldery layer at the frontal edge of the glacier was the chief cause of the formation of the pronounced talus slope shown best in Fig. 46. Its height varied from thirty or forty feet downwards. It gave the glacier the appearance of resting on a pedestal. This appearance was,

I think, with little doubt representative of the real fact in part, but it was also certainly true that the ice extended below the upper edge of the talus slope. The true bottom of the glacier was below its apparent bottom. I succeeded at points in tracing the ice under the talus at least half way down the slope. where the ice was uncovered under the talus its layers were curved upward at high angles, due I suppose to the relief of pressure above and to the resistance of the talus in front (Fig. 48). The concealed ice was less thickly set with débris than

FIG. 48—Diagram intended to illustrate the probable curvature of the layers of ice under the talus in front of the glacier.

the layer above. If there were no other instances than this it might be questioned whether the pedestals on which so many of these northern glaciers seemed to rest were not illusions induced by misinterpretations of slopes of superficial talus derived from special débris-burdened layers of ice that happen to come out at some distance above the true glacial base, but the platforms of débris left by the retreats of some of the glaciers seem to show that there were true pedestals in some cases at least.

Inspection of the face of the glacier, as shown in Fig. 47, shows that certain of the layers of ice jut out over others very sharply. This was found to be a very common phenomenon, not only here but in most of the glaciers of the region. It gave the impression, at first sight, that the upper layers had been thrust forward over the lower ones. If this were the true interpretation, it would be a matter of radical value for it would indicate a mode of motion that has not, I believe, been recognized as a function of glaciers. It became, therefore, in the highest degree important to ascertain whether such was the real nature of the phenomena, or whether the impression was an illu-

sive one. It was very obvious from an inspection of the face of the glacier than wherever débris was embedded in it the radiant energy of the sun was caught and converted into sensible heat and melting was thereby promoted and so the darkened portions of the ice became sunken. From this obvious and very general fact, the suggestion arose that the overjutting layers were due to differential melting faciliated by the débris in the under layer. Observation showed that in most cases the under layer was darkened with débris and that it was therefore disposed to melt more rapidly than the overjutting layer which was usually white and free from débris. There was further evidence of like import in the fact that in some cases—indeed in many cases—the overjutting cornice when traced right and left was found to disappear simultaneously with the disappearance of the débris in the under layer. It cannot be supposed that there would be differential motion that would correspond accurately with the débris in the layers, although there might be a genetic connection between the formation of the layers and the introduction of the débris. Furthermore, in some instances the overjutting portion was too restricted in length and too sharply limited to accord with the hypothesis of differential motion. On the other hand, when it was found that the overjutting layers extended for long distances and that the projection reached two or three feet, and in some cases eight or ten or even fifteen feet, the hypothesis that the phenomenon was due simply to the superior melting of the underlayer seemed unsatisfactory if not untenable.

It occurred to me that if the upper layer moved over the lower layer, rock fragments at the junction of the two layers would give rise to fluting of the under surface of the upper layer as it was forced over it, and that perhaps evidence might be found along this line which would demonstrate the supposed mode of motion. I found upon the south side of the South Point glacier a very pronounced case of overjutting reaching an extent of two to three feet in which the junction plane between the upper and lower layers was corrugated and was marked by a

thin line of earthy and rocky material. The corrugations were not unlike those of the zinc facing of a washboard, except that they were on a much larger scale. I not only found that the débris layer was corrugated, but that for some inches below there were blue laminations of clean ice that were corrugated harmoniously with it. I succeeded in following these backward into the ice sufficiently to show that they were not simply superficial. Presumably they extended some distance along the junction plane. This phenomenon, it will be observed, is not precisely

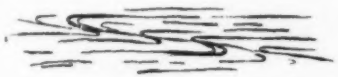


FIG. 49.—Diagram illustrating the phenomena of faulting and drag as seen on the south side of the South Point glacier.

that suggested above, but it has a bearing upon the interpretation of the fluted under surfaces of overjutting layers that were observed in very pronounced development in some of the glaciers yet to be described.

An observation was made on the south side of the glacier that bears upon the same question. On each side of a fracture plane extending obliquely across the ice layers, the laminations were bent toward the plane just as they are in the phenomena of faulting and drag (Fig. 49). There seemed no ground for doubt that there had been motion along the plane of fracture and that the ends of the laminations next to it had been bent backwards by the friction of the two faces. Similar phenomena were observed in several other places.

At another point upon the south side of the glacier there was a wide band of débris-set ice that zigzagged in a very irregular way from the summit of the ice cliff to its base. Fig. 50 is a representation of a sketch made upon the ground. The point at which this appeared was near the extremity of one of the medial moraines, and it seemed probable that this dark zigzag tract represented the junction of the two parts of the glacier that had united on the lower side of one of the nunataks

before described; in other words the two glaciers, instead of fusing, flowed side by side, crowding upon each other mutually and developing this zigzag line of junction. In addition to this very notable and unusual distortion, and in addition to the faulting and drag there were, at not a few points, twisted and contorted laminations indicating varying stresses and differential rates of motion.

FIG. 50.—Sketch intended to illustrate the remarkable zigzag course of a dark layer thickly set with pebbles and bowlders on the south side of the South Point glacier. The upper line of the sketch represents the upper edge of the wall of the glacier and the bottom its base.

On the south side of the glacier a stratum was observed thickly set with bowlders in very much the same manner as the stratum that formed the talus in front. The aneroid indicated that this was about 400 feet higher than the débris layer in front. Its distance back from the front unfortunately was not measured, nor was it traced continuously along the side and shown to be identical with the layer in front, but there seemed little ground to doubt that it was the same, and if so, it is worthy of note as indicating the rapid descent of the débris-bearing layer harmoniously with the descent of the entire glacier. The upper edge of the glacier was measured at a point not far above this and found to be about 550 feet above the base in front.

In respect to the interesting question of recent change in the extent of the ice, the evidence of the South Point glacier seemed very clear so far as it went. It has been remarked that between the glacier and the bay the valley was occupied by glacial wash. In the middle and northern half of the valley this was recent, but in the southern portion there was a terrace ele-

vated from ten feet upwards that was much older. It was very notably weathered and covered with vegetation in the scanty fashion of the region. In particular the bowlders were covered with lichens and were roughened and exfoliated by weathering in a way that indicated considerable antiquity. While comparisons with southern latitudes are liable to error because of the different climatic conditions, it may give some impression of the evidence of aging in the present case to compare these weathered and lichen-covered bowlders with the ruins of mediæval ages. Very possibly, however, they may not exceed a century in age, or even reach that. This older terrace extended to within 100 feet of the present edge of the ice, indeed, at the southeastern curve of the glacier where it turned away from the side of the valley, there was little more than room for the talus slope and the lateral drainage stream between the ice and the old valley débris. In harmony with this evidence, the talus slope of the valley cliffs on the south side, for the most part, was ancient, although somewhat disturbed and freshened at some points near the ice. It would appear, therefore, clear that the glacier has not, within recent times, advanced notably beyond its present position. It may, of course, have been advancing from some point of greater retreat, and may be even now advancing. The sharpness of the talus slope and the fact that it is no greater than it is, is best explained by supposing that the glacier is advancing with exceeding slowness upon the débris which is gradually accumulating at its front.

The Gnome Glacier. This is a smaller glacier occupying a narrower valley. It is only about 1800 feet wide, measured at a point above the terminal slope, according to Lieutenant Peary. It is closely beset with walls of gneiss on either hand, but judging from the erratics which it carries it reaches back to the sandstone series. Red sandstone covers the cliff on the north. The plateau on either side of the valley in which the Gnome glacier lies is capped with a thin stratum of ice, which, at some points, creeps out to the edge of the plateau, from which it falls in broken masses or extends itself downward in little hanging

glaciers. On the south side the edge of the Gnome glacier is quite extensively covered with fallen ice and débris from this source. The foot of the talus slope of the cliff on the north side is in close contact with the border of the glacier and indeed, in portions, has been carried away by it.

The Gnome glacier stops short of Bowdoin Bay by only a few rods, its terminal base lying but little above the sea level.

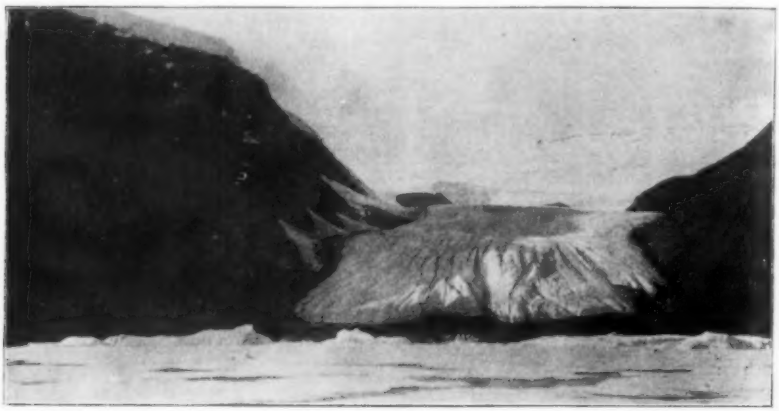


FIG. 51.—The Gnome glacier, seen from the ice of Bowdoin Bay. The dark layer at the base of the glacier and the talus slope are not distinguishable from the surrounding surface. Nunataks are partially shown at the head of the valley where the ice descends from the plateau. The steep border of the ice about them makes them appear as depressions.

It has an abrupt terminal face much like that of the South Point glacier. The upper portion consists of a thick stratum of nearly pure ice, showing indistinct lamination, the middle portion, of alternating dark and light ice, while the lowest exposed portion consists of a dark layer thickly inset with bowlders similar to the dark bowldery layer of the preceding glacier. Below this there is a similar talus slope but of greater height. The day of our visit was sunny and exceptionally warm, and the bowlders were being loosened from the dark stratum of ice and were fall-

ing at short intervals, rendering the ascent of the talus slope imprudent, and its height was therefore not measured. This was by far the most notable exhibition of activity seen in connection with any of the northern glaciers that end upon the land. In no other case during our visit was the loosening and falling of débris more than a rare event. The material contained in this bowldery stratum is in part very coarse, masses of rock several feet in diameter being not uncommon. As in the case of the South Point glacier, the talus slope here conceals the base of the glacier, and it was not ascertained how much of the talus slope represented a subglacial accumulation and how much merely a superficial concealment of the glacier's base. It was observed here, as in the preceding case, that the lamination of the ice under the talus slope stood at high angles, and had its strike approximately parallel to the face of the glacier, and this seems to be the prevalent fact in similar cases.

The laminæ of the ice are frequently twisted and distorted, and horizons of faulting and overthrust appear to be common, but they were inaccessible to close observation. The outjutting layers sometimes project two or three feet beyond those below. It would seem from the unconformity of the bent and crumpled layers that shearing action had taken place.

There are no abandoned moraines on the front or sides of the glacier. The sides of the valley showed some freshening and disrupting above the present edge of the ice, indicating that it had recently stood somewhat higher, but beyond this there was no evidence of any recent difference in extension. Beyond the exceptionally rapid melting of the face at the time of our visit there were but limited signs of activity.

T. C. CHAMBERLIN.

THE CLASSIFICATION OF THE UPPER PALÆOZOIC ROCKS OF CENTRAL KANSAS.[1]

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INTRODUCTION.

RECENT studies of the geology of eastern central Kansas, in connection with the preparation of geologic maps of that region

[1] Published by permission of the Director of the United States Geological Survey.

for the United States Geological Survey, have acquainted the writer with interesting facts in reference to the description and classification of the Upper Palæozoic rocks of Kansas.

The early geologists of the state, Hawn, Swallow, Meek and Hayden engaged in a spirited controversy, not only in regard to the correlation of the geological formations of this part of the state, but also as to whom belonged the honor of first announcing the discovery of the Permian rocks in Kansas. Major Hawn stated that his first impression that the rocks in question might be of Permian age was obtained from a letter written by Mr. Meek, September 3, 1857.[1] On January 19, 1858, at the request of Meek and Hayden, a record was made at the Smithsonian Institution in which is mentioned "forms indicating Permian both in Kansas and the region of the Black Hills."[2] In determining the date of the first scientific publication of the discovery of Permian fossils in Kansas neither of these records should be considered. The first public announcement before a scientific society of the identification of Permian fossils in Kansas was made by Professor G. C. Swallow in a letter read by Professor B. F. Shumard before the St. Louis Academy of Science, on February 22, 1858.[3]

[1] Am. Jour. Sci., 2d series, Vol. XXVI., p. 188; *ibid.*, Vol. XLIV., p. 38. Trans. Acad. Sci. St. Louis, Vol. II., p. 511.

[2] Am. Jour. Sci., 2d series, Vol. XLIV., 1867, pp. 38, 39. See *ibid.*, Vol. XXVI., 1858, p. 188, and Trans. Acad. Sci. St. Louis, Vol. II., p. 511.

[3] See Trans. Acad. Sci. St. Louis, Vol. I., pp. 111, 112. The letter, which was dated February 18, contains the identification of several species collected by Major Hawn. Professor Swallow states: "I can have no doubt that the rocks are Permian, since the proof is very conclusive to my mind. . . . . All of the described fossils, with perhaps two exceptions, are identical with Permian species of Russia and England, while all of the new species appear to be more nearly allied to Permian forms than to any other." At the same meeting a portion of a paper by Professor Swallow and Major Hawn was read, entitled "The Rocks of Kansas, with descriptions of new fossils from the Permian formation in Kansas territory." The reading of this paper was concluded at the following meeting on March 8 (Trans. Acad. Sci. St. Louis, Vol. I., pp. 112, 113; and pp. 173-197). An abstract of the paper was read at the Baltimore meeting of the American Association for the Advancement of Science, May, 1858, and appeared in the Am. Journal of Science, November, 1858 (2d series, Vol. XXVI., pp. 182-188). Also published in Proc. Am. Assoc. Adv. Science, Vol. XII., 1859, pp.

Apparently the first published announcement of the Permian age of the Kansas fossils was a letter from Professor G. C. Swallow to Professor J. D. Dana, dated February 16, 1858, and printed in the March number of the *American Journal of Science and Arts*[1] Swallow mentioned some ten European Permian species; these or closely allied species he had identified in Major Hawn's collection and he stated "I can but feel that the above is sufficient to justify us in the decision that they are *Permian*."

On March 2d, Professor James Hall read a paper by Meek and Hayden before the Albany Institute, describing a small collection of fossils "from near the mouth of the Smoky Hill fork of the Kansas River" concerning which is the statement: "We think there is scarcely room to doubt that it [the formation] is of Permian age."[2] A letter from Meek and Hayden making brief mention of the discovery was read the same day before the Philadelphia Academy of Natural Sciences.[3]

After reviewing the various statements referring to the discovery of Permian rocks and fossils in Kansas, it appears that to Professor Swallow belongs the credit of first announcing the fact before a scientific society and publishing a notice of the discovery in the leading scientific periodical of the country.[4]

214–221, where Professor Swallow says, "The Coal-measures occupy a belt along the eastern end of the territory, extending westward as far as Fort Riley. West of the Coal-measures the Permian strata are developed over a wide zone stretching across the territory from north to south" (p. 220).

[1] 2d series, Vol. XXV., p. 305*.

[2] Trans. Albany Inst., Vol. IV., p. 76. The paper is entitled "Descriptions of new organic remains from northeastern Kansas indicating the existence of Permian rocks in that territory," pp. 73–89. This paper was noticed in the May number of the Am. Jour. Sci. (2d series, Vol. XXV., p. 442).

[3] Proc. Acad. Nat. Sci., Philadelphia, Vol. X., pp. 9, 10.

[4] Professor Hayden stated that extras of the Albany Institute paper were distributed two days after it was read, so that the paper "was actually published on the 4th of March;" but he seems to have been in error in stating that the March number of the American Journal of Science, which contained Professor Swallow's letter, was issued "between the 4th and 10th of March" (Am. Jour. Science, 2d series, Vol. XLIV., 1867, p. 38, f. n.).

The Proceedings of the Albany Institute for March 2, 1858, following the remarks

TOPOGRAPHY.

The region under consideration is a belt of country varying in breadth from fifty to seventy-five miles, extending across the state from south to north in an approximate northerly direction. Topographically, it is a region with high hills which generally have rounded slopes capped by escarpments of massive limestone and flint. The valleys are narrow, and the landscape as a whole presents an appearance quite at variance with the preconceived idea of the plains of Kansas. As my knowledge of the country increases, I am led to see the resemblance that it bears, in miniature, to the Colorado plateau of the west [Utah and Arizona]. Its topographic features appear to be similar to the Ozark uplift of southern Missouri which has been well described by Nason as follows: "While at the base of these steep-sided hills we cannot escape the feeling that we are among mountains. A climb up the slope dispels the idea however. Instead of a commanding view from the summit of the divide we look forth upon what in the distance appears to be a plain stretching away on every hand. The mountain crests rise to the same level as far as the eye can reach."[1]

This elevated tract of land known as the "Flint Hills" crosses the southern boundary of the state on the line of Cowley and Chautauqua counties and then extends in a northerly direction with a breadth varying from twenty-five to forty miles. A view from the summit of the divides reveals an extensive plateau in which the streams have eroded many small valleys, leaving numerous mesas and other interesting topographic features due to the alternation of layers of flint and massive limestones with shales and shaly limestones. Along the valleys of the rivers and

of Professor Hall upon Mr. Meek's paper, contain the following statement: "Mr. Gavit called attention to the fact that, in the last number of Silliman's Journal, Professor Swallow makes a similar announcement as to the identity of certain fossils of Nebraska with those recognized as Permian" (Trans. Albany Inst., Vol. IV., p. 248). Finally, Professor James D. Dana wrote me: "I have no doubt that the number for March, 1858, was out and off by the 1st [of March] if not before" (Letter of March 28, 1895).

[1] Geol. Surv. Missouri, Vol. II., 1892, p. 86.

larger streams and extending well up toward the heads of their branches are numerous trees; but on the upland of the plateau nothing appears save the native prairie grass. At numerous points are extensive views of most interesting landscapes which are especially beautiful when clothed with the bright green grass of early summer.[1]

As the summer advances the grass is frequently turned brown by the hot, dry weather so that during August and September the ground is parched and barren, and it is not at all strange that the early explorers of Kansas described the region as a "desert." Professor Broadhead has called attention to some of the interesting topographic features of this region and has suggested that it "might appropriately be termed the Permian Mountains."[2] In a recent paper Professor Haworth has admirably described the topographic features of eastern Kansas, and concisely stated that its terraced topography is due to "a condition which seems dependent principally upon the more or less regular occurrence of alternating heavy beds of soft shales with light beds of harder limestones and sandstones."[3] The professor also speaks of the beauty of the scenery[4] along the Kansas River and the "magnificent bluffs"[5] which line the upper part of its valley.

[1] Among other places the writer would especially mention Blue Mount at Manhattan, looking up the canyon of the Kansas River, which presents a scene of surpassing beauty. Fine views may also be obtained at various places on the southern side of the Kansas River between Manhattan and Junction City; at numerous places in Wabaunsee county south of Alma and southeast toward Eskridge; in Chase county southwest of Cottonwood Falls, on the southeastern side of Cottonwood River, and in the southern part of the state in the eastern portion of Cowley and western portion of Chautauqua county.

[2] Trans. St. Louis Acad. Science, Vol. IV., Pt. III., 1883 (?), p. 484. Again, on page 491, occurs this statement: "The group of the Permian Mountains forms an interesting study, the strata are easily traced, and the scenery afforded is very fine and the views very extensive." An abstract of this paper was published in the Am. Jour. Science, 3d series, Vol. XXII., 1881, pp. 55–57, and the above quotations appear on pp. 55 and 57 respectively.

[3] Kansas Univ. Quarterly, Vol. II., 1894, p. 134.

[4] *Ibid.*, p. 131.

[5] *Ibid.*, p. 134.

Principal rivers.—Two river systems have cut approximately east and west valleys through this plateau, nearly at right angles to the trend of its flint ridges. The Smoky Hill and Kansas Rivers have cut the valley in the northern part of this range, while the Cottonwood River has eroded a similar valley through its central part. The great value of these two valleys in determining the character and stratigraphic relations of the geologic formations composing the upper Palæozoic and lower Mesozoic rocks of Kansas was early appreciated, consequently these two great sections are classics in the literature of the Permian and Permo-Carboniferous rocks of Kansas. In a recent article the writer has discussed the geology of the Kansas River section, particularly from Manhattan to Junction City; identified and correlated as far as possible the various beds of that section as described by Meek and Hayden, Swallow, and Hay, and given lists of fossils which characterize the various divisions of the section.[1] The present paper proposes to consider in a similar manner the classic section of the Cottonwood Valley and in addition, to define briefly the formations into which the writer has divided the upper Palæozoic rocks of Kansas.

The Cottonwood River valley.—About seven miles below the city of Emporia, the Cottonwood River enters the Neosho and reaches the Arkansas River near Fort Gibson in the Indian Territory; consequently the Cottonwood River forms a part of the great drainage system of the Arkansas. For more than twenty miles from its mouth, to a point near Ellinor, the Cottonwood River flows through a broad, fertile valley with low hills in the distance. But above Ellinor it rapidly narrows, except where tributary streams enter it, to a valley one or two miles in width, lined on both sides with steep hills which are generally capped by a prominent escarpment of massive limestone or flint. This type of valley continues westerly as far as the junction of the South Cottonwood River with the Cottonwood, two miles west of Marion; and for some forty miles along the main line of the

[1] Kansas River section of the Permo-Carboniferous and Permian Rocks of Kansas, Bull. Geol. Soc. America, Vol. VI., pp. 29–54.

Atchison, Topeka & Santa Fé Railroad from Ellinor to a point near Peabody. The bluffs on the southern side of the river are generally higher and more continuous than those on the northern side. This is well shown in the bluff extending from the vicinity of Cottonwood Falls southwest to Florence, where for a distance of twenty-three miles there are but two decided breaks, one of which occurs at Clements formed by Coyne Branch, and the other at Cedar Point where Cedar Creek enters the Cottonwood. From the northern side of the valley different prominent strata of limestone are seen forming terraces near the summit of the bluff. This is especially noticeable along the bluff from Cedar Point to the summit opposite Florence. A similar bluff, but higher and steeper, extends for twenty miles along the south side of the Kansas River, from Manhattan to Junction City, broken only by the two valleys formed by McDowell and Clark Creeks. As far as my observation goes, the southern bank of many of the streams in this part of Kansas is steeper than the northern, and Professor Haworth tells me that such a statement applies in a general way to all the rivers of Kansas.

DESCRIPTION OF THE GEOLOGICAL FORMATIONS. — THE WABAUNSEE FORMATION.

In the classification of the rocks into formations, primarily for use in areal geology, it has been the general intention to include in a formation a series of strata, which may be characterized by their fossils and which have similar lithologic characters.

In the lower valley of the Cottonwood, as well as along the adjacent portion of the Neosho, are several rather massive beds of limestone between which are calcareous, argillaceous and arenaceous shales with an occasional thin stratum of coal. The limestones of this formation cap the low bluffs along the river valley to Ellinor, where a higher limestone, known as the Cottonwood, appears near the top of the bluff, which, dipping westerly, is carried nearly down to the level of the river about one and one-half miles west of Strong City; then begins to rise again

until it reaches the top of the high bluff 200 feet above the river at Elmdale. As a result of this folding the Wabaunsee formation extends thirteen miles farther up the Cottonwood River to the vicinity of Clements.

This series of limestones and shales is well exposed along the Neosho River below and above Emporia, and especially to the north, in the eastern and northern portions of Wabaunsee county. There are excellent outcrops in the bluffs along Allen, One Hundren and Forty-Two Mile, and Elm Creeks in the northern part of Lyon county; on Elk, Dragoon and Mission Creeks in southern and eastern Wabaunsee county, and particularly on Mill Creek in the northern part of the county; and on the bluffs of the Kansas River from Wabaunsee to the vicinity of Ogden in Riley county. I have considered the base of this formation as defined by the top of the Osage coal horizon,[1] and the top by the base of the massive limestone known locally as the Cottonwood, Alma and Manhattan limestones. Mr. Charles R. Keyes has proposed the name Missouri formation for the upper Coal Measures of Iowa and Missouri,[2] but did not clearly indicate the upper limit of the formation. The deposits forming the upper coal measures of Kansas are principally of the same age as those in northwestern Missouri, and, if we consider the Osage and Silver Lake coal horizon as the upper limit of the Missouri formation in Kansas, then the Wabaunsee formation will directly succeed the Missouri formation. The formation covers one-half of Wabaunsee county and,

[1] This is near the line of division between the upper Carboniferous and Coal Measures of Professor Mudge. The Professor states that the dividing line between these formations "is not clearly defined or easily fixed . . . . . Plants and coal are the best evidences, and even these are not strongly marked" (First Bien. Rept. [Kans.] State Board Agri., p. 71, and see p. 86 for place of the Osage coal). Professor Mudge, however, did not understand the northern and southern extent of this horizon, as was shown later by Professor St. John (Third Bien. Rept. [Kans.] State Board Agri., p. 585) and Hay (Eight *ibid.*, p. 132). Finally Professor Haworth has shown that on the Kansas River the Silver Lake Coal, 125 feet above the Topeka, is the equivalent of the Osage Coal (Kan. Univ. Quart., Vol. III., pp. 304, 305 and Plate XX).

[2] Iowa Geol. Surv., Vol. I, 1893, p. 114. *Ibid.*, Vol. II, 1894, Plate III, and p. 137. Missouri Geol. Surv., Vol. IV, Pal. Mo., Pt. I, 1894, p. 82.

on account of the excellent exposures along nearly every stream in the eastern and northern portions of the county, I would propose that it be called the *Wabaunsee formation.*

Early geologic explorations.—The rocks of this formation along the Kansas River, especially from Mill Creek westward, were carefully examined by Meek and Hayden in the summer of 1858, and a paper describing the geology of the region traversed appeared the following January.[1] During the same summer Dr. Newberry studied this series of rocks as exposed along the Santa Fé road, on his return from the Ives exploring expedition of the Colorado River of the West, from Santa Fé to Fort Leavenworth, crossing the Neosho River at Council Grove.[2]

In the summer of 1859 Dr. Newberry again crossed the same formations as exposed along the route from Independence, Mo., to Santa Fé on his way to join the Macomb exploring expedition and described to some extent the rocks and fossils found along Dragoon Creek and on the high ground to the west.[3]

Palæontology.—The calcareous and argillaceous shales frequently contain numerous specimens of fossils representing a

[1] Proc. Acad. Nat. Science, Philadelphia, Vol. XI., p. 8; see particularly pp. 14 and 18. A part of this paper including the "general section of the rocks of Kansas valley" appeared in the Am. Jour. Sci., May, 1859 (2d series, Vol. XXVII., pp. 424–432).

[2] Dr. Newberrys's observations on this trip were published in 1861 in the Report upon the Colorado River of the West, explored in 1857 and 1858 by Lieut. Joseph C. Ives. Geological Report by Dr. J. S. Newberry, Chapter X., Geology of the route from Santa Fé to Fort Leavenworth, p. 102. See particularly pp. 110–115. Meek and Hayden's "General section of the rocks of the Kansas Valley" from Manhattan to the Cretaceous is copied on pp. 112–114.

[3] Report of the Exploring Expedition from Santa Fé, New Mexico, to the junction of the Grand and Green Rivers of the great Colorado of the West in 1859, under the command of Capt. J. N. Macomb, with Geological Report by Professor J. S. Newberry. See Chapter I., and especially pp. 16–21. Although Dr. Newberry's report was finished in 1860, it was not published until 1876, but in his Prefatory Note of June, 1875, we find these words: "Precisely as written in 1860." A brief account of this trip appeared in the September number of the Am. Jour. Science, for 1859 (2d series, Vol. XXVIII., pp. 298, 299) where Dr. Newberry states that "from Wellington to Cottonwood and Turkey Creek the Permian was constantly found in the hill-tops, but the valleys were excavated down to the Carboniferous" (p. 298).

considerable number of species; but in the massive limestones the number of species and individuals is usually smaller.

From the exposures of shales and limestones on Mill Creek, the following species were obtained, which are arranged in the order of their relative abundance and may be considered the characteristic fossils of the formation:

1. *Chonetes granulifera*, Owen.
2. *Productus* (*Marginifera*) *splendens*, Norw. and Pratt.
3. *Productus semireticulatus*, (Martin) de Koninck.
4. *Productus cora*, d'Orbigny.
5. *Spirifer* (*Martinia*) *planoconvexus*, Shum.
6. *Fusulina cylindrica*, Fischer.
7. *Athyris* (*Seminula*) *subtilita*, (Hall) Newb. = *A. argentea*, (Shep.) Keyes.
8. *Pugnax uta*, *Marcou* (Marcou) Hall and Clarke.
9. *Productus nebrascensis*, Owen.
10. *Hustedia mormonii*, (Marcou) H. and C.
11. *Septopora biserialis*, (Swallow) Waagen.
12. *Rhombopora lepidodendroides*, Meek.
13. *Spirifer cameratus*, Morton.
14. *Pinna peracuta*, Shum.
15. *Phillipsia scitula*, Meek and Worthen.
16. *Derbya crassa*, (Meek and Hayden) H. and C.
17. *Meekella striato-costata*, (Cox) White and St. John.
18. *Chonetes Flemingi*, (according to Keyes) Norw. and Pratt.
19. *Allorisma Geinitzii*, Meek (?)
20. *Campophyllum torquium*, (Owen) Meek?
21. *Chonetes glabra*, Geinitz = *C. lævis*, Keyes.
22. *Productus symmetricus*, McChesney.
23. *Spiriferina kentuckensis*, Shum.
24. *Enteletes hemiplicatus*, (Hall) H. and C.
25. *Dielasma bovidens*, (Morton) H. and C.
26. *Orbiculoidea nitida*, (Phillips) H. and C.
27. *Myalina subquadrata*, Shum.
28. *Allorisma subcuneatum*, M. and H.
29. *Aviculopecten occidentalis*, (Shum.) Meek and Worth.

30. *Straparollus* (*Euomphalus*) *subrugosus*, Meek and Worth. = *S. catilloides*, (Con.) Keyes.

The bluffs along the Kansas River near Manhattan afforded me the following additional species:

31. *Fistulipora nodulifera*, Meek.
32. *Fusulina cylindrica*, Fischer, var. *ventricosa*, M. and H.
33. *Lingula umbonata*, Cox.
34. *Orbiculoidea manhattanensis*, (M. and H.) H. and C.
35. *Nuculana bellistriata*, Stevens, var. *attenuata*, Meek. (?)
36. *Dawsonella Meeki*, Bradley (?)
37. *Lophophyllum proliferum*, (McChes.) Meek
38. *Cladodus mortifer*, Newberry and Worthen.

In the lower part of the formation, from exposures along the Kansas River below the mouth of Mill Creek and extending to the vicinity of Topeka, the following additional species were obtained:

39. *Bellerophon sublævis*, Hall.
40. *Myalina Swallovi*, McChesney.
41. *Allorisma* (*Sedgwickia*) *topekænsis* (Shum.) Meek.
42. *Myalina perattenuata*, M. and H.
43. *Productus punctatus* (Mart.) Sowb.
44. *Allorisma* (*Sedgwickia*) *Geinitzii*, Meek.
45. *Edmondia ovata*, Meek.
46. *Schizodus curtus*, M. and W.
47. *Nuculana bellistriata* (Stevens) Meek.
48. *Allorisma granosa* (Shum.) Meek.
49. *Macrodon tenuistriata*, M. and W.
50. *Modiola* (?) *subelliptica*, Meek.
51. *Productus pertenuis*, Meek.
52. *Edmondia aspinwallensis*, Meek.
53. *Entolium aviculatum* (Swallow) Meek.
54. *Solenomya radiata*, Meek and Worth.

As will be seen from the above fauna this formation clearly belongs in the upper part of the Carboniferous to which system these rocks have generally been referred.

Meek and Hayden's classification.—In Meek and Hayden's paper

of 1859 it was proposed to divide the upper Palæozoic rocks into the Permian and Permo-Carboniferous.[1] They did not indicate precisely this line of separation, but it seems probable that their Permo-Carboniferous division included the upper part of the Wabaunsee formation.[2]

Newberry's classification.—It is evident that Dr. Newberry in his early explorations regarded the rocks of this formation as belonging to the Carboniferous, for he stated in 1860 that "at Dragoon Creek [probably on the Santa Fé trail in the southeastern part of Wabaunsee county where the upper part of the course of Dragoon Creek is eroded in rocks belonging to the Wabaunsee formation, while the upper part of the bluffs belong to the overlying formation] we reach the extreme summit of the Carboniferous formation, and first meet with those which may be regarded as distinctly Permian."[3]

[1] Also see the following statement of Meek and Hayden: "We are inclined to the opinion that the entire series, from near the top of the Lower Permian of Professor Swallow's and Mr. Hawn's section, down even lower than the horizon where they draw the line between the coal measures and the lower Permian, should be regarded as intermediate in age, and as filling the hiatus between the Permian and upper coal measures of the Old World. . . . This intermediate series might be very appropriately termed the Permo-Carboniferous group, to indicate its relations both to the Permian and Carboniferous rocks" (Am. Jour. Science 2d series, Vol. XXVII., January 1859, p. 35).

[2] See PROSSER: Bull. Geol. Soc. Amer., Vol. VI., p. 51, and notice the line of separation indicated with a question on p. 53. The authority for this statement may be found in Hayden's article in the Amer. Jour. Science, 2d series, Vol. XLIV., 1867, p. 37, where he states that "Meek and Hayden regarded the beds . . . . down so far as to include most, if not nearly all, of Professor Swallow's Lower Permian, as an intermediate connecting series between the Permian and Coal Measures, which, if worthy of a distinct name at all from the latter, should be called Permo-Carboniferous."

[3] Rept. Explor. Exp. 1859, Macomb, p. 19. It is not clear from the context whether by "Permian," Dr. Newberry meant the base of the Permo-Carboniferous, or the base of what he called "true Permian;" but the former seems to have been his interpretation, for on p. 16, in enumerating localities containing numerous fossils, he mentions "Permo-Carboniferous at Dragoon Creek and Wilmington" [name of southeastern township of Wabaunsee county, with town of same name in the southeastern corner on Soldier Creek] and "true Permian on the hill-tops east of Council Grove [which would be some twenty miles southwest of the Permo-Carboniferous localities], and on Cottonwood Creek." Also in describing the region toward Council Grove is the statement that "over a considerable area in this vicinity the highlands are occupied by what may be considered true Permian strata, while the valleys of all the water-courses are exca-

At this time Dr. Newberry clearly recognized the difficulty of separating the Carboniferous and Permian systems by any sharp line, and he said, "From this interlocking of the Carboniferous and Permian faunæ, it is evident that the line of separation between the two formations must continue to be debatable ground; and as there is, in fact, a group which contains a mingled fauna—in truth, a Permo-Carboniferous group—we must introduce this new member into the geological series, or fix upon some conventional line which shall form the boundary between the summit of the Carboniferous and the base of the Permian formations."[1]

Comparison of the Wabaunsee formation with Swallow's section.—Professor Swallow in his Preliminary Report on the Geology of Kansas divided the rocks of eastern Kansas into 256 beds which were referred to the Quarternary, Tertiary, Cretaceous, Triassic, Permian and Carboniferous systems.[2] In his section the rocks which we have referred to the Wabaunsee formation were described from exposures occurring principally along the Kansas River, Mill Creek and adjacent country. As the limits of the Wabaunsee formation have been indicated, it includes the rocks from the top of Swallow's bed, No. 154, up to the base of bed, No. 80. The greater part of the formation belongs to the upper part of the Carboniferous system of Swallow, which he called "Formation *a*—Coal Measures," including the larger portion of his "Stanton Limestone series" and all of the following series in ascending order, "Chocolate Limestone" and "Upper Coal series." In addition to the above rocks the Wabaunsee formation includes the four beds forming the base of Swallow's "Lower

vated to and into the Permo-Carboniferous, or, as I have called them, Upper Carboniferous strata" (p. 20). Again he says, "the Permian magnesian limestones occupy the general surface, but are cut through by the valleys of the draining streams. Below them are exposed strata containing *Orthisina umbraculum; Productus Calhounianus;* spines of a species of *Archæocidaris*, regarded by Professor Swallow as identical with *A. Verneuiliana*, King; a small *Athyris*, and a *Rhynchonella;* all of which belong rather to the Carboniferous than to the Permian fauna" (p. 21).

[1] *Ibid.*, p. 20.

[2] Prel. Report, Geol. Survey, Kansas, 1866, section of the rocks in eastern Kansas, pp. 9–29.

Permian," Nos. 84–80, to which he assigned a thickness of forty-two feet, and claimed that on Mill Creek the base of the Lower Permian was separated from the Carboniferous by unconformability.[1] In general it is not difficult to identify the beds which Swallow referred to the Permian, but those of the Carboniferous are not as clearly defined. Swallow gives the total thickness of the beds which I have included in the Wabaunsee formation as 546 feet, while from my estimate of the exposures along the Kansas River the formation has a thickness of probably 575 feet.

As stated above, the greater part of this formation consists of a series of limestones alternating with argillaceous and calcareous shales which it is not necessary to consider in detail in this article. The upper part of the Wabaunsee formation is more important in reference to the geological classification of these rocks, since the line drawn by Professor Swallow separating the Carboniferous from the Permian occurs forty-two feet below its top. Professor Swallow considered bed, No. 84, of his section, which he named the "dry bone limestone," the base of his Lower Permian; next above came bed No. 83, composed of "bluish-brown marls, one foot;" then No. 82, the "Cotton rock, five feet," above which was No. 81, composed of thirty-one feet of shales and marls which is the top of the Wabaunsee formation. These shales are capped by a massive limestone, six feet thick, called bed No. 80 by Swallow and named the "*Fusulina* limestone" on account of the abundance of this fossil. Professor Swallow states that beds "Nos. 82, 83 and 84, are sometimes represented by a bluish-gray and buff porous magnesian limestone, ... containing numerous Permian *Acephala* and *Zaphrentis* and small *Spirifer*," and he gives the locality as the Cottonwood.[2]

This limestone is in general very prominent in the bluffs along the Cottonwood River from the vicinity of Ellinor to within

[1] See section on p. 16, and the following statement on p. 44: "Nos. 85–95, from the sections near Manhattan are not found in the Mill Creek sections, where No. 84 rests directly upon the Fusulina shales, No. 96."

[2] *Ibid.*, p. 16.

three miles of Clements. A mile west of Strong City it is carried below the surface by a synclinal fold, but it reappears west of Simmons Creek three miles west of Strong City, where it forms a prominent ledge on the northern side of the valley which is conspicuous from the Atchison, Topeka & Santa Fé trains. It also forms a prominent ledge on the southeastern bank of the river below and above Elmdale, as well as on the northwestern side, some distance from the river until within four miles of Clements, where it becomes more conspicuous on the Blackshere ranch (Sec. 12, 20 S., 6 E.). This ledge, a massive bluish-gray stratum in places seven feet or more in thickness, frequently breaks on the edges into large blocks, with sharp angles and rough, jagged surface, which usually weather to a color not dissimilar to that of bleached bones, hence the name "dry bone limestone" is not especially inappropriate. Professor Swallow repeatedly stated that the limestones all through the rocks which he called Permian were strongly magnesian and regarded their chemical composition as an important character in separating the Carboniferous and Permian systems. The professor was in error in this particular and must have considered the limestones to be magnesian from their general appearance since a chemical analysis of them fails to reveal magnesia in any considerable amount.[1] This erroneous view in reference to their chemical composition was noticed by Professor Mudge,[2] and the error is very evident from an examination of the table of

[1] This is well shown by the following analysis of a specimen of the "dry bone limestone" from Manhattan, by Mr. Warren Finney, who kindly analyzed a series of these limestones for me:

SiO_2	2.34 per cent.
Fe_2O_3	0.03 "
$CaCO_3$	97.46 "
$MgCO_3$	1.02 "
Al_2O_3	trace
	100.85 "
CO_2	44.34 "

[2] First Bien. Rep. [Kansas] State Board Agri., 1878, Geology of Kansas, p. 70, where in describing the Permian and Upper Carboniferous he said, "Some of the lime has been called magnesian, but analysis has failed to show, in more than a single

"Analyses of Kansas building stones" prepared by Dr. S. W. Williston for the Columbian Exposition.[1]

Professor Swallow claimed that the main reason for drawing the line of separation between the Carboniferous and Permian at the base of the "dry bone limestone" was the fact "that the Permian fossils come down in force to this line and but few go below, while a few species only of Carboniferous fossils are found above it."[2] In beds, Nos. 82, 83 and 84, I have found but few fossils and those are not especially Permian types, while it will be shown that in the Cottonwood shales of the succeeding formation there are abundant specimens of characteristic Carboniferous species. The small *Spirifer* mentioned by Professor Swallow in this limestone on the Cottonwood[3] is *S. cameratus*, Morton which I have not found at a higher horizon.

Comparison with Haworth and Kirk.—In the paper describing the Neosho and Cottonwood River sections by Professor Haworth and Mr. Kirk, this limestone is called No. 12, and its extent is well shown along the Neosho River from five miles above Emporia to Dunlap. It is also accurately noted on the Cottonwood from the vicinity of Ellinor to Strong City, but it was not recognized on its reappearance three miles farther west.[4]

THE COTTONWOOD FORMATION.

Succeeding the Wabaunsee formation is a massive yellowish to light gray limestone with a maximum thickness of six feet capped by yellowish calcareous shales fourteen feet thick which together have been called the Cottonwood formation.[5]

Geologic section of the Cottonwood formation.—The thickness of the formation is about twenty feet, and it is well exposed in the

instance, over 5 per cent. of magnesia." This statement is not correct for the limestones of the Permian, but well expresses the chemical composition of the lower limestones.

[1] Mineral Resources, U. S., for 1893, pp. 563–565.

[2] Prel. Rep. Geol. Surv., Kansas, p. 44.

[3] *Ibid.*, p. 16.

[4] Kan. Univ. Quart., Vol. II., pp. 112, 113 and Pl. IV., Figs. 2 and 3.

[5] PROSSER: Bull. Geol. Soc., Amer., Vol. VI., p. 40.

Fox Creek quarry and bluff, one mile west of Strong City. At this locality there is the following section:

No. 4. Blocky limestones from 1′ 6″ to 2′ in thickness separated by shaly partings. This bed is referred to the succeeding formation (Neosho).

No. 3. Yellowish, calcareous shales which contain plenty of calcite (?) nodules but no fossils. Between 6′ and 7′.

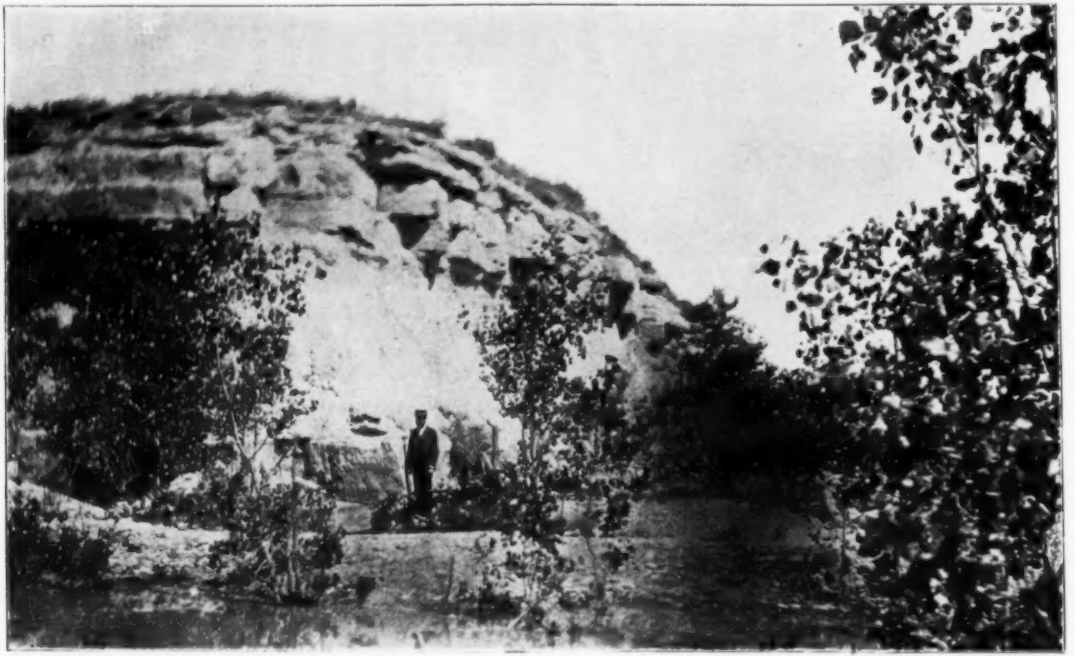
No. 2. Similar shales containing plenty of fossils which in the lower part are extremely abundant. 7′ 2″.

No. 1. Massive limestone. Stratum not fully exposed. 4′ 8″ +.

Distribution and character of the Cottonwood limestone.—Along the bluffs of the Cottonwood River this limestone first appears as a prominent ledge near Ellinor and on account of folding may be followed up the Cottonwood River to Crawfordsville or Clements. It may be traced along the principal branches of the Cottonwood River as follows: Up the South Fork to three miles south of Bazaar; along Middle Creek for eight miles; and up Diamond Creek to Hymer. It is the most valuable dimension stone in the state and at various places are extensive quarries which afford an excellent opportunity to study the limestone and its overlying shales. Some of the more important quarries are those on the north side of the river between two and three miles east of Strong City; the Lantry & Sons' quarry in the city limits, and the Fox Creek quarry one mile west of Strong City. On the south side are those of the Rettiger Bros., Du Chanois and Jones two and one-half miles east of Cottonwood Falls, and the Perrin quarry in Cottonwood Falls, while farther up the river near Clements are the quarries of D. Y. Hamill. The limestone on a fresh fracture is yellowish-gray in color weathering to a light gray and generally appears along the side of the moderately steep bluffs as a series of rectangular blocks that have been separated from the main ledge. The stone is very strongly calcareous containing about 85 per cent. of calcium carbonate and less than 2 per cent. of magnesian carbonate.[1]

[1] Dr. S. W. Williston reports the following analysis:

Insoluble matter	8.57 per cent.
Oxides of iron and alumina	3.62 "
Calcium carbonate	84.72 "



No. 1. View of the Cottonwood limestone and shales capped by the blocky limestones at the base of the Neosho formation. Fox Creek quarry west of Strong City.

The amount of flint contained in the rock varies. In some localities it is scarcely perceptible while in others the quantity is sufficient to make the rock comparatively valueless for economic purposes. There are very few fossils, with the exception of *Fusulina cylindrica*, Fischer, which is extremely abundant in the upper part of the stratum. The quarrymen call these fossils grains of wild rice, and on account of their great abundance Professor Swallow called the stratum the "*Fusulina* limestone."[1] This limestone forms one of the most important features in the stratigraphy of the Upper Palæozoic rocks of Kansas and in many respects is as valuable for stratigraphic purposes as the Tully or Corniferous limestones in the Devonian of New York.

Fauna of the Cottonwood shales.—The yellowish overlying shales, which may be called the Cottonwood shales, constitute one of the most fossiliferous horizons of the Carboniferous, although there are but a few species that are extremely abundant. The immense number of fossils in this shale was noted by Professor Haworth and Mr. Kirk, who stated that in the shale of the Rettiger quarries "marine invertebrate fossils are unusually abundant,"[2] but in general this, its most striking characteristic wherever exposed, seems to have been overlooked.[3]

Wherever the shale has been exposed for some time to the action of the atmosphere large numbers of loose fossils perfectly

Magnesian carbonate - - -	1.75	"
Sulphates - - - -	.90	"
	99.56	"

Mineral Res., U. S. for 1893, p. 563. The samples came from the Rettiger Bros.' quarry, the crushing strength being 6800 lbs.; weight per cubic foot 161.6 lbs.; and the specific gravity 2.59.

[1] Prel. Rep. Geol. Surv. Kans., p. 16.

[2] Kans. Univ. Quart., Vol. II., p. 113.

[3] Professor Broadhead probably noticed the fossils of this shale, but his reference is quite indefinite. The Professor mentions quarries in the Cottonwood Valley containing "about six feet of very good building stone," probably the Cottonwood limestone, and says, "the associated shale beds abound in fine fossils, including *Prod. semireticulatus; Hemp. crenistria;* a large variety of *Chonetes granulifera* and *Athyris subtilita*, *Archæocidaris*, and a Crinoid" (Trans. St. Louis Acad. Sci., Vol. IV., Pt. III., p. 492).

preserved may be found. This is especially true of *Chonetes granulifera*, Owen, which in places may be collected by the hundreds from the top of the underlying limestone, or in the soil formed by the decomposed shale.

In the Cottonwood shales at the Rettiger Bros.' quarry the following species were collected:

1. *Chonetes granulifera*, Owen. (aa)[1]
2. *Derbya crassa*, (M. and H.) Hall and Clarke. (a)
3. *Athyris* (*Seminula*) *subtilita*, (Hall) Newb. = *A. argentea*, (Shep.) Keyes. (a)
4. *Productus semireticulatus*, (Martin) de Koninck. (a)
5. *Meekella striato-costata*, (Cox) White and St. John. (c)
6. *Productus nebrascensis*, Owen. (r)
7. *Aviculopecten McCoyi*, M. and H. (r)

   Imperfectly preserved specimens which seem to agree closely with this species. There are heavy costæ which show the base of spines and these ribs are separated by two or three smaller plications.
8. *Straparollus* (*Euomphalus*) *subrugosus*, Meek and Worth. = *catilloides*, (Con.) Keyes. (rr)
9. *Septopora biserialis*, (Swallow) Waagen. (rr)
10. *Rhombopora lepidodendroides*, Meek. (rr)
11. *Lophophyllum proliferum*, McChesney. (rr)
12. *Fusulina cylindrica*, Fischer. (rr)
13. *Aviculopecten occidentalis*, (Shum.) M. and W. (rr)
14. *Dielasma bovidens*, (Morton) H. and C. (rr.)
15. *Chætetes* cf. *carbonarius*, Worth. (rr)

In addition to the above list the following species were obtained from exposures of the Cottonwood shales near Cottonwood Falls or Strong City:

16. *Phillipsia scitula*, M. and W. (?) (rr)
17. *Crinoid* plates and stem.
18. Fish plate.

[1] The relative abundance of the species is indicated in the following manner: a=abundant; aa=very abundant; c=common; r=rare; rr=very rare, when but one or two specimens are found.

19. *Archæocidaris* plates and spine.
20. *Bryozoa* sp.
21. *Glauconome* sp.

From the Hamill quarry near Clements the two following species were obtained:

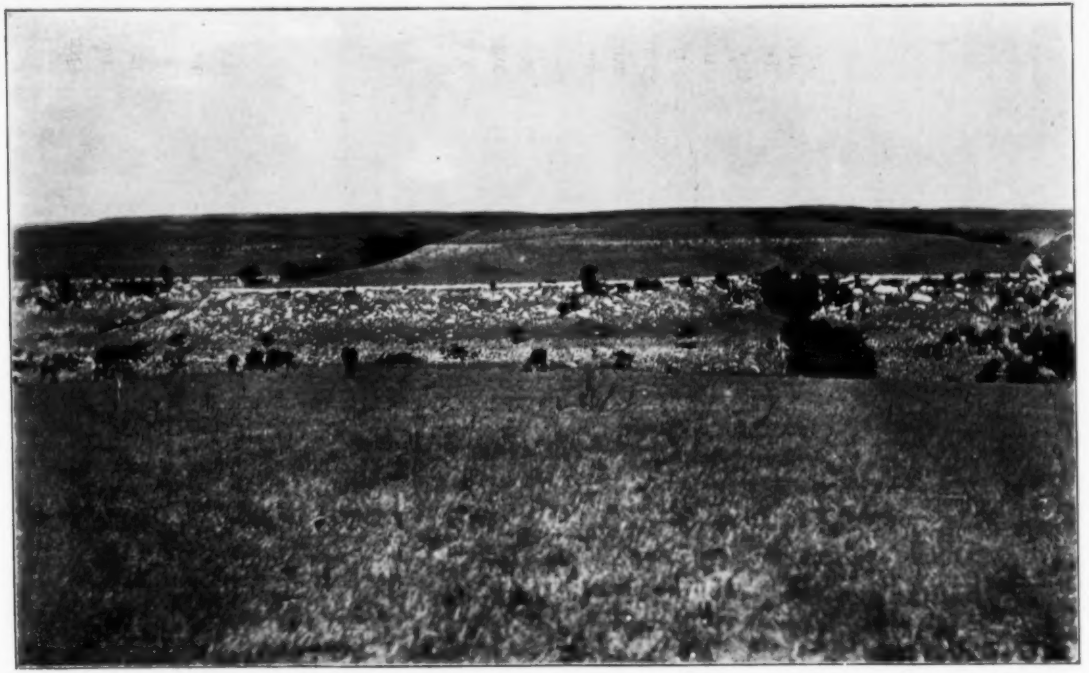
22. *Productus cora*, d'Orbigny. (rr)
23. *Fistulipora nodulifera*, Meek. (rr)

A study of the above fauna will clearly show it to be one of the Upper Carboniferous of the Mississippi Valley and Great Plains, although many of the species occur in the deposits called Permo-Carboniferous and an occasional one has been reported from the so-called Permian rocks of the United States. A comparison of the fauna of the Wabaunsee formation with that of the Cottonwood will reveal the fact that while the former contains more than twice as many species as the latter, which proportion will probably not be materially changed by further search, still every species of the Cottonwood formation with the exception of *Aviculopecten McCoyi*, M. and H., and *Chætetes* cf. *carbonarius*, Worth, which are doubtfully identified, occurs in the Wabaunsee formation, consequently, as far as the biologic evidence is concerned, there is no support for placing the Cottonwood formation in a system or even series, distinct from that of the Wabaunsee.

Former descriptions of the Cottonwood limestone.—The Cottonwood limestone was among the first stones of the state to be used for construction where strength and durability were desired, but it is not known to the writer at what date it was first called the "Cottonwood stone." It forms bed No. 80 of Swallow, which he called the "*Fusulina* limestone" and described as "buff, porous and magnesian," six feet thick, exposed at "Manhattan, Cottonwood Falls and Mill Creek."[1]

It forms the summit of Blue Mount and Mount Prospect at Manhattan and the bluffs along Mill Creek above Alma, consequently it appears that Professor Swallow correlated the several exposures of this limestone correctly although he made no reference to its extent, in the descriptive part of the work. Later

[1] Prel. Rept. Geol. Surv. Kansas, 1866, p. 16.



No. 2. Line of the Cottonwood limestone on the north side of the Kansas River west of Manhattan. Characteristic appearance of the limestone along the bluffs of streams.

writers seem to have overlooked his conclusions and there has been much confusion concerning the correlation of the prominent limestones of the Kansas and Cottonwood valleys. Professor St. John referred to the extensive quarries near Strong City, where he stated "the ledge is extensively wrought."[1]

Professor Haworth and Mr. Kirk described briefly the Cottonwood limestone as it occurs on the Neosho River from Dunlap toward Council Grove and on the Cottonwood River near Cottonwood Falls, and called it Limestone System No. 13 "of their section."[2]

Geographic extent of the Cottonwood limestone.—In general it seems that the stratigraphic importance of the Cottonwood formation has been overlooked. The constant character of the limestone, its line of outcrop frequently marked by a row of massive, light gray rectangular blocks filled with *Fusulina cylindrica* and capped by a yellowish shale in which occur immense numbers of *Chonetes granulifera*, *Athyris subtilita*, *Productus semireticulatus* and a few other fossils constitutes one of the most distinctive formations yet seen in the upper Palæozoic rocks of Kansas, and is very valuable for the purposes of stratigraphic and areal geology. Recently there have been general statements in reference to its extent across the state,[3] and such distribution is very probable; although I believe it has actually been traced but part of the distance. In the summer of 1894

[1] Third Bien. Rep. [Kansas] State Board Agri., Vol. VIII., 1883, p. 584.

[2] Kans. Univ. Quart., Vol. II., pp. 112, 113, Pl. IV., Figs. 2 and 3. Also, see *ibid.*, Vol. III., p. 279.

[3] A pamphlet on the "Mineral Resources of Kansas," prepared for the Columbian Exposition, speaks of the Cottonwood Falls limestone as "the most extensive limestone bed in the state, and can be traced as one continuous formation across the state from north to south" (p. 18). The author, however, did not know the stratigraphic relations of the Cottonwood limestone, for he considered as one and the same the limestone at Manhattan in the Kansas valley and that at Florence in the Cottonwood valley, while as a matter of fact that at Florence is entirely different in character and is stratigraphicaily 250' above the Cottonwood limestone. The "Report of the Kansas Board of World's Fair Managers, 1893," describes a limestone, which, from the localities mentioned (Manhattan, Alma, Strong City, etc.) is evidently the Cottonwood stone, that forms a "horizon which is traceable across the state from east of Marysville [Beattie, Marshall Co.], on the north, to Cambridge, Cowley county, on the south."

the writer traced this formation from the northern part of Greenwood county into Riley county north of the Kansas River. There are good exposures of the limestone in the eastern part of Chase county on the South Fork of the Cottonwood River and its eastern branches. It may be traced up the Cottonwood River to Clements; from Strong City to the vicinity of Ellinor, then across the divide into the Neosho valley near Dunlap, when it follows the bluffs of the river about half the distance to Council Grove, then turns northeasterly across the high land of Wabaunsee county, passing near Bushong and the heads of the various streams in eastern Wabaunsee to Eskridge at the head of Dragoon Creek. From Eskridge it continues north on the high land near the head of Mission Creek, reaching Mill Creek near Alma. It continues northerly across the divide toward Wabaunsee, then follows the high bluffs along the south side of the Kansas River to Manhattan and extends up the river valley to the vicinity of Ogden, about five miles below Fort Riley. Along the entire extent of this line which is about one half the distance across the state, the formation is clearly marked wherever there are exposures, and its distinctive characters are very constant.[1]

CHARLES S. PROSSER.

[1] The author first called attention to the important stratigraphic character of this formation and briefly outlined its course across eastern central Kansas in 1894 (see Bull. Geol. Soc. Amer., Vol. VI., p. 40, and particularly footnote ‡). Later Professor Haworth has indicated in a general way the outcrop of the Cottonwood Falls limestone across the state (Kans. Univ. Quart., Vol. III., April, 1895, Pl. XXI. and p. 279).

[To be continued.]

EDITORIAL.

THE seventh summer meeting of the Geological Society of America, held at Springfield, Mass., will be remembered as one in which matters were transacted with promptness and commendable dispatch, amidst very agreeable surroundings. The principle of considering first only those papers whose authors were in attendance, and of reading the papers of absent members only when called for, proved highly satisfactory. Those who had come long distances to the meeting were able to present their papers properly, and at the same time were held closely to the time allowance they had themselves chosen. And it is to be hoped that similar methods will obtain at all future meetings. The session was short, lively and interesting. The president of the society, Professor N. S. Shaler, and the secretary, Professor H. L. Fairchild, are to be congratulated upon the success of the meeting. Of the nineteen papers upon the programme thirteen were presented by their authors, the others being read by title. Professor B. K. Emerson explained the geology of the central portion of Massachusetts, upon which he has been engaged for twenty-five years, and by means of elaborately detailed maps, which he has prepared for publication, and with the aid of others he has devised for his class room, he made clear the geological structure of the region.

Previous to the meeting he had conducted an excursion over the same ground, and had shown some of the chief exposures of metamorphosed palæozoic strata, whose character he has already demonstrated. Upon this trip he was assisted by Professor T. N. Dale and Professor Wm. H. Hobbs, who have been at work upon adjacent districts. The success of this excursion and of the short, impromptu one, which Professor Emerson kindly conducted on the afternoon of the last day of the meeting, has suggested the

desirability of making the chief function of the summer meetings the geological excursion, or excursions, and the presentation of such papers as may be germane to the geological problems there encountered. The greater number of papers consequently crowded into the winter meetings could be satisfactorily considered and discussed if they were judiciously classified and were presented in such sections of the society as could be held at the same time without interference; papers of general interest being read before the society in general session. A partial subdivision of papers was attempted at the last winter meeting, in Baltimore, and promised well.

A list of the papers presented at the Springfield meeting follows. J. P. I.

* * *

1. GEORGE M. DAWSON and R. G. MCCONNELL:
   On the Glacial Deposits of Southwestern Alberta, in the Vicinity of the Rocky Mountains.
2. C. H. HITCHCOCK:
   The Champlain Glacial Epoch.
3. WARREN UPHAM:
   Drumlins and Marginal Moraines of Ice-sheets.
4. H. L. FAIRCHILD:
   The Glacial Genesee Lakes.
5. B. K. EMERSON:
   The Geology of Old Hampshire County in Massachusetts.
6. N. H. DARTON:
   Notes on Relations of Lower Members of Coastal Plain Series in South Carolina.
7. N. H. DARTON:
   Resumé of General Stratigraphic Relations in the Atlantic Coastal Plain from New Jersey to South Carolina.
8. ARTHUR HOLLICK:
   Cretaceous Plants from Martha's Vineyard. Results Obtained from an Examination of the Material Collected by David White in 1889.
9. WILLIAM B. CLARK:
   On the Eocene Fauna of the Middle Atlantic slope.
10. R. T. JACKSON and T. A. JAGGAR:
    Arrangement and Development of Plates in the *Melonitidæ*.

11. GEORGE P. MERRILL:
On Asbestos and Asbestiform Minerals.

12. WM. H. HOBBS:
Pre-Cambrian Volcanoes in Southern Wisconsin.

13. A. CAPEN GILL:
A Geological Sketch of the Sierra Tlayacac, in the State of Morelos, Mexico.

14. C. H. GORDON:
Syenite-Gneiss (Leopard Rock) from the Apatite Region of Ottawa County, Canada.

15. J. F. KEMP:
The Titaniferous Iron Ores of the Adirondacks.

16. J. C. BRANNER:
The Decomposition of Rocks in Brazil.

17. W. M. DAVIS:
The Bearing of Physiography on Uniformitarianism.

18. C. R. VAN HISE:
Analysis of Folds.

19. N. S. SHALER:
On the Effects of the Expulsion of Gases from the Interior of the Earth.

PUBLICATIONS.

Summary of Current pre-Cambrian North American Literature.[1]

Smith,[2] in 1892, reports on the Archean Rocks of Hunters Island and adjacent country. The rocks are divided into Laurentian and Huronian, and the latter subdivided into Coutchiching and Keewatin. The main occurrences of the Laurentian rocks are the Kawagansikok, Poo-Bah, Hunters Island and Saganaga areas. The Kawagansikok granite is in places fine grained and nearly devoid of mica and hornblende; in other places is a muscovite-granite; in others is garnetiferous granite-gneiss. The rock is frequently cut by coarse pegmatite veins. The Poo-Bah area is usually a coarse hornblende syenite, but in places it merges into a finer grained hornblende-granite. The Hunters Island rocks are usually biotite-granites, but the biotite is often replaced by, or associated with muscovite, hornblende or chlorite. At Agnes Lake angular fragments of Mica-schist or gneiss are found in the granite. At various places occur hornblende-granites. There are other isolated areas of granite which break through the Coutchiching rocks which cannot certainly be said to be of Laurentian age. The granites as a whole usually have a foliated character.

The Coutchiching series covers a large area in the northwestern part of the district, and several small areas are found to the eastward. The Couchiching rocks are usually mica-schists. In general their schistosity is parallel to that of the granites, but at Conmee Lake there is a discrepancy between the two which may indicate a structural unconformity or a fault. The mica-schist is cut by granite apophyses at various places. If foliation is taken as thickness the series would vary from 1.386 miles to 5.548 miles. However the mica-schists are regarded as repeated by folding. Although having isoclinal dips, there is a considerable variation which may indicate such folding.

Keewatin rocks are confined to the southeastern part of Hunters Island. They consist of quartzites, soft gray schists, quartz-porphyries,

[1] Continued from p. 236, Vol. III. JOURNAL OF GEOLOGY.

[2] Report on the Geology of Hunters Island and Adjacent Country, by W. H. C. SMITH. Ann. Rep. Geol. Sur. of Canada, for 1890–1, Vol. V., Part 1, G., pp. 5–76, 1892.

felsite, sericite-schists, conglomerates, altered traps, hornblende-schists and other green schists. Occasionally contained in them are areas of banded jasper and hematite. On the north side of Cache Bay is a felsitic conglomerate in contact with a coarse-grained hornblende-granite. Beds of dolomite are associated with this conglomerate. The breadth of the Keewatin series gives no certain criterion by which to estimate its thickness. The dip shows an apparently simple synclinal structure.

As to the relations of the Laurentian to the Huronian series, they have a general parallel schistosity, and there are many phenomena suggestive that the granitic and syenitic type is of igneous eruptive origin, later than the Huronian, but the hornblendic and micaceous phases of these granites may be rocks of different determinable ages, the discovery of which may throw light not only on the genesis of the Laurentian, but on its relations to the overlying Couchiching and Keewatin. Cutting both Laurentian and Couchiching rocks are diabase dikes in such attitudes as to leave little doubt that they were intruded since the last folding, on which assumption their geological age is post-Keewatin.

Grant,[1] in 1894, gives a general account of the geology of the Gunflint lake district. In Ts. 65 and 66 N., Rs. 4, 5 and 6 W., are Keewatin rocks, including the usual types—volcanic tuff, greenstone-schists, greenstone, and the Ogishke conglomerate. The Saganaga granite is intrusive in the Keewatin. The more crystalline schists of the district have been called Couchiching and Vermilion. It, however, appears that these rocks in this area are a more crystalline phase of the Keewatin, and that they owe their crystalline nature to the proximity of intrusive granite.

The iron-bearing rocks of Akeley Lake lie upon the Keewatin greenstone to the north, and on the south are overlaid by the great gabbro mass. The belt has a width of from 300 to 1300 feet, and a dip varying from 20° to almost vertical, but averaging 45° to 50°. Where widest, it has an average dip of 30°, which would make a maximum thickness of 650 feet. The iron ore is a titaniferous magnetite.

The Animikie rocks are little disturbed, except locally, having an

[1] Preliminary Report of Field Work during 1893 in Northeastern Minnesota, by U. S. GRANT, 22d Ann. Rep. Geol. and Nat. Hist. Sur. of Minn, Part IV., pp. 67–78, 1894.

average dip of 8° or 10° a little east of south. The Animikie beds are interleaved with diabase sills. These give parallel east and west ridges, the south sides of which are gentle slopes, and the north steep mural descents. This topography has led Lawson to the conclusion that the apparent large number of sills are due to monoclinal faulting of fewer layers, but of this there is no evidence. The Animikie strata are divided as follows: an upper or graywacke-slate member, 1900 feet thick, composed of slates and graywackes, with fine-grained quartzites and quartz-slates; a middle or black slate member, 1050 feet thick, composed mainly of black slates, apparently carbonaceous, with a fine grained siliceous and flinty layer at the base 60 feet thick; and a lower or iron-bearing member, composed largely of jaspery, actinolitic, siliceous and magnetitic slates, usually thinly laminated, and some beds of cherty iron carbonate. The Akeley Lake rocks, first called Pewabic quartzite, are similar to the Gunflint iron-bearing rocks and different from the Pewabic quartzite of the western Mesabi range, and if these iron-bearing rocks are put at the base of the Animikie, there seems to be serious objection to regarding them as the basal quartzite, and the equivalent of the quartzite of the western Mesabi range. No true quartzite is found at the base of the Animikie in the Akeley Lake area, but the iron-bearing rocks at Gunflint Lake rest directly upon the Keewatin.

The quartzites of Pigeon Point are lithologically similar to the quartzite at the top of the graywacke-slate member, and are supposed to be equivalent to it. The igneous rocks are all intrusive. The diabase sills sometimes have a thickness of 100 feet. They have not been found in contact with nor to extend into the gabbro below. The great Keweenawan gabbro of the district has a varying mineralogical composition, sometimes being composed almost entirely of feldspar, thus forming anorthosite, and again being exceedingly rich in olivine. This gabbro includes fragments of the Animikie slates, and was found directly overlying and in contact with the uppermost member of the Animikie, thus showing it to be of post-Animikie age. Associated with the coarse-grained gabbros are finer grained rocks including gabbros, olivine-gabbros, norites and olivine-norites, which have been called muscovado. These are slightly older than the main mass of gabbro, which is seen cutting and including fragments of them.

The acid eruptive rocks, called augite-syenite by Irving, including reddish, hornblendic, granitic rocks, are found cutting the gabbro. In

passing toward the granitic rocks, at first a few small acid dykes are seen. These increase in frequency in approaching the central mass of the granite, and at the edge of the mass apophyses can be traced directly from the granite into the gabbro. The dykes are not finer grained as a whole or at their edges, than the main mass, thus indicating the heated condition of the gabbro when the dykes were intruded. It is concluded that while the granite is of later date than the gabbro, it is not much later, and was perhaps intruded before the complete solidification of the basic rock.

Culver,[1] in 1894, describes the rocks of Itasca county, Minn. The Pokegama quartzite was found to extend from the north end of Pokegama Lake northeasterly to the rapids of Prairie River. This rock is flat lying, with low southerly or southeasterly dip, and seems to have been bowed into a series of low flat arches. The lower beds are fine grained, hard and massive, although broken into cubical blocks. In the upper portions of the quartzite in many places is found a considerable quantity of iron ore. In cross section there are alternately sheets of ore and sheets of quartz. In the hand specimen these quartz layers show no grains. The structure is porous, and the quartz is usually stained red. Both the ore and quartz layers are exceedingly irregular, and are often interrupted or cut by each other.

The Prairie River granite lies in a belt parallel to the Pokegama quartzite. It contains some bodies of schist, which are taken to indicate that the granite is eruptive. Thrust planes are numerous, and generally have either vertical or very steep dips.

On Big Fork River, a few miles above the mouth of Rice River, diorite was found, and also at Koochiching Falls in the Rainy River. Greenstones constitute the chief exposures between Rice River and Big Falls. They comprise beds which are purely eruptive, other beds which are consolidated tuffs, and other phases which it is not possible to place certainly in either class. The mica-schists constitute an immense series, extending on the Big Fork River from a point twelve miles below Little Falls to within fifteen miles of Rainy River. At various places the mica-schist is cut by granite. In passing from the mica-schist to the granite, the mica-schist becomes veined with a granite, which gradually increases in

[1] Notes on the Geology of Itasca county, Minn., by G. E. CULVER. Geol. and Nat. Hist. Sur. of Minn., 22d Ann. Rep., Part VIII., pp. 97–114, 1894.

abundance, until granite becomes the predominating rock. The schists are also cut by dikes of greenstone.

Elftman,[1] in 1894, publishes his field notes on Northeastern Minnesota. In the region north of Snowbank Lake are found conglomerate, mica-schist, sericite-schist, argillite, diabase, conglomeratic greenstone, porphyry, augite-granite and hornblende-granite. The former of these granites has heretofore been called gray syenite, and the latter red syenite.

On the west shore of Boot Lake, in the S.W. ¼, N.W. ¼, Sec. 21, T. 64 N., R. 8 W., are several large dykes of porphyry cutting the graywacke and schist. In the S.W. ¼, N.E. ¼, of the same section, on the east side of a long point, dikes of granite are found cutting the conglomerate in all directions, and distorting the strata in a very complicated manner. In the conglomerate are bowlders up to four feet in diameter of gneiss, slate, diabase and granite, the last being scarcely distinguishable from the granite which cuts the conglomerate. In some instances a granite dike was found to cut some of the large bowlders of the conglomerate, when the contact between the dike and the granite bowlders could not easily be determined. The exact relations of the hornblende-granite and the augite-granite to each other, and the relations of the latter to the sedimentaries, are still doubtful. The gray granite has not been found in contact with the schists, argillites and conglomerates, and it is cut by the red granite, which also cuts the schist. The hornblende-schists and mica-schists of Snowbank and White Iron Lakes grade into argillaceous slates and conglomerates, the schistose character being most fully developed at the contact with the granite.

The Animikie actinolite-magnetite-schists are derived from rock containing an original iron carbonate. As the formation thins out toward the east, and passes under the gabbro, it becomes more crystalline. Near the contact of the gabbro augite and olivine occur intimately associated with the actinolite and magnetite of the Animikie schists. The black slates have been changed into biotite-schist in the proximity of the gabbro. These slates disappear before the Dunke River is reached, having been removed at the time of the gabbro intru-

[1] Preliminary Report of Field Work during 1893 in Northeastern Minnesota, by A. H. ELFTMAN. Geol. and Nat. Hist. Sur. of Minn., 22d Ann. Rep., Part XII, pp. 141–180, 1894.

sion. The Pewabic quartzite at the bottom of the Animikie decreases in thickness as Birch Lake is approached from the west, and in the vicinity of Iron Lake disappears entirely. From this locality eastward the iron-bearing rock rests upon the granite. It is concluded that the Pewabic quartzite between Birch Lake and Gunflint Lake belongs to the middle iron-bearing member of the Animikie.

In Ts. 62 N. and 61 N., Rs. 10 W. and 11 W., occurs a heavily bedded olivine gabbro. In going from the northern and southern limits of the gabbro toward the center of the area it is noticeable that the ferro-magnesian minerals decrease and the feldspar increases in proportion, until in the center of the mass occur numerous knobs and areas, a mile or more in extent, composed of plagioclase rock or anorthosite, which are regarded as segregations. In the center of the mass the rock has greater coarseness of texture, and also more of a stratified appearance, arising from the arrangement of the constituent minerals in bands. The mineral and chemical composition of the various parts of the formation correspond to the known rules which govern the cooling of liquid magmas, and the whole is regarded as a batholitic intrusion rather than a surface flow.

Red rocks, comprising augite-syenite, quartz-porphyry, felsite, etc., occur in the vicinity of Greenwood Lake, and were followed to the shores of Lake Superior, making together one prominent group of rocks.

The dark gabbros of Irving, the diabases and the amygdaloids are placed in another group, called the diabase group. The anorthosites of the coast of Lake Superior, described by Lawson as pre-Keweenawan, and newly discovered masses back from the coast, are found to be detached blocks from the great gabbro mass enclosed in and underlain by the black gabbro, as previously held by Irving and Winchell. The latter rock is considered as the effusive equivalent of the great basal gabbro. After the aggregations of feldspar had separated from the gabbro magma, and were floating around in it, they were ejected in portions of the unsolidified magma, and being lighter than it, floated near the surface, and are found only near the top of the first outburst of lava or black gabbro. Later, when the rock was somewhat eroded, the feldspar knobs projected above the surrounding rocks, and later were covered by the flows of the red rock group. Therefore, the conclusion of Lawson that the anorthosite forms a pre-Keweenawan terrane, is rendered valueless.

In chronological order the Keweenawan of the north shore of Lake Superior can be divided into gabbro, diabase, red rocks and later dikes.

Grant,[1] in 1894, describes the lowest beds of Grand Portage Island, north coast of Lake Superior, as consisting of arenaceous slates, sandstones and conglomerates, the fragments of the latter being quartz, quartzite, siliceous slate, a dark flinty rock, red quartz-porphyry and red granite. These are in part clearly waterworn. All of the pebbles of the conglomerate can be matched in the Animikie strata near by. These beds are regarded as the lowest of the Keweenawan in this locality, and the material in the conglomerate shows that the Animikie clastics had been subjected to metamorphosing forces before Keweenawan time, and, as agreed by all Lake Superior geologists, that there was an erosion interval between the two. As the red quartz porphyry and the granite have been shown to be intrusive in the Animikie, and also in the gabbro and diabase of Pigeon Point and Grand Portage, it is concluded that these intrusions occurred at a date later than the Keweenawan.

COMMENTS.

It is to be presumed that this last statement applies only to the Keweenawan of the locality discussed.

Lawson,[2] in 1893, describes a multiple diabase dike near the mouth of White Gravel River on the northeast coast of Lake Superior, where occur in a breadth of fourteen feet no less than twenty-eight vertically intrusive sheets of diabase, ranging in thickness from one inch to six and one-half inches, separated by twenty-seven sheets of granite, ranging in thickness from a quarter of an inch to eight inches. The dikes anastomose and are connected at various places, showing that they are due to a single intrusion. The granite is seemingly homogeneous, there being no differentiation of structure or of mineral composition. It is believed that the splitting of the granite was due directly to the invasion of the diabase magma. This occurrence is comparable to the complex parallel invasion of the schistose rocks of the Ontarian system by granite.

[1] Note on the Keweenawan Rocks of Grand Portage Island, North Coast of Lake Superior, by U. S. GRANT. Am. Geol., Vol. XIII., No. 6, pp. 437–438, 1894.

[2] Multiple Diabase Dike, by A. C. LAWSON. Am. Geol., Vol. XIII., No. 5, pp. 293–296, May, 1894.

Spurr,[1] in 1894, gives an account of the rocks of the Mesabi district, and particularly of the iron-bearing rocks.

The oldest formation of the district is the Keewatin, the most common rock of which is green schist, but associated with this, especially near the granites, are hornblende-schists and mica-schists. The schists have a regional cleavage, which is nearly uniform in trend, about N. 70° E. and nearly vertical. Next in age to the Keewatin schists is the hornblende-granite of the Giants Range. This range has an average width of about ten miles, and its direction is the same as that of the schistosity of the Keewatin rocks. The granite is intrusive in the schists, as shown by numerous fragments imbedded in it, by stringers of the granite in the schists, and the metamorphism of the schists adjacent to the granite.

Unconformably upon the former is the Animikie series. The Animikie series has no marked folding, slaty cleavage or schistose structure. The rocks of the series are in a gentle southern monocline, in a direction perhaps 10° or 15° East of South. This monocline has gentle undulations, with axes parallel to its dip, and in the Virginia area has been faulted. The amount of disturbance is greater adjacent to the central part of the district, where are found the Keweenawan rocks. It is probable that the weight of the Keweenawan rocks has produced a sinking in the area south of the Animikie, and that this has produced the tilting. The Animikie series may be divided into three chief members: the Pewabic quartzite, the iron-bearing member and the upper slates. The Pewabic quartzite is a fragmental rock, indurated by the enlargement of quartz grains. It occasionally passes into a fine-grained conglomerate. The iron-bearing member is composed of peculiar rocks, presenting no resemblance to the Pewabic quartzite or to the upper slate. The upper slates are of great thickness, and have at their base an impure limestone, often dolomitized or sideritized.

The part of the iron-bearing member from Pokegama Falls to Embarass Lake is called the Western Mesabi range, that from Embarass Lake to Gunflint Lake, the Eastern Mesabi range, and from Gunflint Lake east, the International Boundary area. The description of the iron-bearing member below applies to the western part of the district. It has a thickness varying from 500 to 1000 feet, with an average of about 800 feet. The dip varies from less than 10° to as much as 30°,

[1] The Iron-bearing Rocks of the Mesabi Range in Minnesota, by J. EDWARD SPURR. Geol. and Nat. Hist. Sur. of Minn., Bull. X., p. 268, with geol. maps, 1894.

the width of the formation varying correspondingly from two or three miles to less than half a mile, the average width being one mile, and the average dip 10°. Resting upon the iron-bearing member is a great thickness of fine-grained slates, at the base of which is locally an impure dolomitic limestone. When this limestone is present, the contact between the iron-bearing member and upper slate cannot be distinctly located.

The least altered phase of the iron-bearing member is a rock called taconyte, which consists of a background of cryptocrystalline, phenocrystalline and chalcedonic silica, in which are numerous granules. These are composed of glauconite, siderite, hematite, magnetite, limonite and cryptocrystalline silica, in the very freshest phase the two former being predominant. The granules in one of these fresher phases by analyses showed about 35 per cent. of siderite and 65 per cent. of glauconite, or about 22 per cent. of ferrous oxide in the form of siderite; and about 10 per cent. of ferrous and ferric oxide, two-thirds being the former in the glauconite. Other analyses gave similar results. Analyses showed a very little calcium and magnesium. In the freshest phase found were seen, in thin section, probably detrital original grains of carbonate, recognized by their cleavage as calcite or dolomite. From the taconyte, by a complicated series of metasomatic changes, there have developed cherts and jaspers, which are sideritic, hematitic, magnetitic or actinolitic, or two or more of these combined. During the process the chert and iron oxides were largely concentrated in alternating bands. The cherts and jaspers are frequently concretionary and brecciated. They have often a prismatic jointing and horizontal parting.

These transformations were caused by downward percolating waters, carrying as the chief agents oxygen and carbonic acid, and as subordinate agents sulphuric acid and alkalies. In the changes from glauconite and siderite to the oxides, there was an important shrinkage of the mass, and this has resulted in the brecciation, prismatic jointing horizontal parting and banding. The prismatic jointing is analogous in its formation to the shrinkage of basaltic columns of lava. The horizontal parting is caused by a later shrinkage along the least diameters of the columns formed by the prismatic jointing. The banding is due to the removal of silica and the entrance of iron along the parting.

The ore deposits rests upon the Pewabic quartzite, or upon the

hard and little altered iron-bearing rock, in areas of especial weakness or disturbance, as (1) actual fault lines, (2) incipient fault lines, (3) apices of anticlinal folds, and the troughs of synclines. These are places of fracture and where abundant waters were converged, often form wide areas, and therefore where large quantities of iron were supplied. The downward percolating water, taking iron carbonate in solution, precipitated the iron as oxide in those places where there was an abundance of oxygen, and at the same time took the silica in solution, thus forming the ore bodies. Between those of the largest size and the small local concentrations there are all gradations. The larger deposits of ore occur where they are protected from glacial erosion on the north by a hard ridge of the Keewatin rocks, and especially when the hard rocks give slight elevations on either side, so as to present a basin-like depression.

The glauconite in origin is believed to be the same as modern glauconites, that is, it has developed within foraminifera and other minute shells, as a result of a reaction between the organic matter within the shells and fine ferriferous clay. As the formation contains only a small quantity of ordinary fragmental quartz grains, it formed in water at a depth beyond which much of these material was deposited. As its upper horizon grades into limestone, this indicates a further subsidence of the area, so that the distance from the shore line became so great that very little mechanical detritus was furnished, and the deposit was made up of calcareous matter.

In the eastern Mesabi district the Animikie strata are pierced and intermingled with the northern border of the Keweenawan rocks, so that their normal attitude is often much disturbed. With this change the iron of the iron-bearing member becomes largely magnetic and the silica hard and crystalline. It is concluded that the iron before Keweenawan time was here in the state of sesquioxide, and that the heat of the igneous Keweenawan rocks and the disturbances of the Animikie series produced by them are the causes of the change of the sesquioxide of iron to its magnetic form. Thus the normal process of decomposition and concentration was brought to a close, and this probably explains the poverty of this part of the district in large ore deposits.

At the base of the Cretaceous are ferriferous detrital deposits derived from the Animikie. A study of these indicates that the metasomatic processes had gone far before Cretaceous time, although they have since continued to the present time.

COMMENTS.

This account of the Mesabi district is fairly satisfactory. The discovery of a large amount of glauconite in the least altered phase of the iron-bearing rock is an important additional point in the genesis of the rocks of the iron-bearing formations of the Lake Superior region. However, the conclusion that all of the iron of the iron-bearing formation, even in the Mesabi district, is derived from glauconite hardly seems established. In the least altered phase of the rocks, one which shows comparatively little or no evidence of change, according to the analyses given, a larger proportion of the iron is in the form of siderite than in the form of glauconite. Also in the least altered phase of rock, what were regarded as original detrital grains of calcite or dolomite were seen. These were taken to be one of these minerals from their cleavage, but as the cleavage of siderite is of an identical character, and as the analyses of the least altered phases of the rock show abundant siderite, and but a minute quantity of magnesium and calcium, it seems far more probable that this original material is siderite. There is no reason, so far as the writer can see, why a part of the iron should not have formed as siderite, and another part as glauconite, even in the Mesabi district itself, and it is wholly possible that in the Lake Superior region, in the Upper Huronian of which the Animikie is a part, in one district glauconite may have been the predominant form, while in another siderite was the more abundant.

It is of interest to note that the succession of rocks in the Mesabi district is the same as previously determined in the Penokee district and that the processes of development of the various phases of the altered ferruginous rocks, the agents which did the work, the resultant types and the concentration of the ore bodies, as given for the Mesabi district, are remarkably similar to those which have been ascertained to apply to other districts of the Lake Superior region.[1] The frequent presence of the ores in basins is regarded as due to the more resistant character of the surrounding Keewatin rocks, rather than to

[1] The Penokee Iron-bearing Series of Michigan and Wisconsin, by ROLAND DUER IRVING and CHARLES RICHARD VAN HISE. Tenth An. Rep., U. S. G. S., Chap. V., pp. 347–458, 1890, and Mon. XIX., U. S. G. S., Chap. V., pp. 182–295, 1892.

The Iron Ores of the Lake Superior Region, by C. R. VAN HISE. Trans. Wis. Acad. Sci., Arts and Letters, Vol. VIII., pp. 219–223, December 1891.

The Iron Ores of the Marquette District of Michigan, by C. R. VAN HISE. Am. Jour. Sci., Vol. XLIII., pp. 116–132, February 1892.

their original concentration in such places. The fact that the southern dipping monclinals are folded into a series of slight anticlines and synclines, combined with the presence of iron ore in basins, seems to me to be strong evidence that many if not all the larger ore bodies in the Mesabi district as elsewhere were concentrated in pitching synclinal troughs. The recent development of the mines confirm this conclusion and give no evidence that the large ore deposits have formed at anticlines or faults. The following laws, worked out in reference to the other districts of the Lake Superior region, appear also to apply to the Mesabi district, and if so, they may be said to be universal for this region.

(1) The iron ores always rest upon a relatively impervious basement. This basement may be a shale, a slate, a quartzite, an amygdaloid, a volcanic tuff, an intrusive mass or a dike, a less porous layer of the iron-bearing formation, or any combination of these. (2) Large ore bodies are chiefly found where the impervious basements, simple or complex, form pitching troughs. (3) These pitching troughs are particularly likely to bear unusually large ore bodies when the iron-bearing formation has been brecciated or shattered by folding or some other process, so as to allow ready entrance to percolating waters. Within the troughs the iron-bearing and oxygen-bearing solutions have been converged and mingled, thus precipitating the iron oxide.

Spurr,[1] in 1894, discusses the stratigraphic position of the Thompson slates of northeastern Minnesota. These have heretofore been correlated with the Animikie slates. However, almost every phase of slate of the Thompson series can be duplicated by the less altered phases of the Keewatin schists of the Mesabi range. In the vicinity of the Mississippi River the Thompson series becomes partly crystalline, being changed into sericitic, micaceous, hornblendic, staurolitic or garnetiferous schists which correspond exactly with the green schists of the Keewatin. The cleavage of the Thompson series marks a distinctively pre-Animikie disturbance. The trend of the cleavage corresponds with that of the schistosity of the Keewatin of the Mesabi range, and it is thought that the two were developed at the same time. The Thompson series has undergone a considerable folding, and in this respect also more resembles the Keewatin than the Animikie slates,

[1] The Stratigraphic Position of the Thompson Slates, by J. E. SPURR. Am. Jour. Sci., Vol. XLVIII., No. 294, pp. 159–165, August 1894.

which are in an undisturbed condition. The Thompson series is therefore regarded as unconformably below the Animikie, and is provisionally correlated with the Keewatin.

COMMENTS.

No petrographical descriptions are given of the Thompson slate and of the Keweenawan green schists which are said to be similar. The essential likeness or unlikeness of such fine-grained rocks as the Thompson slates and the Keewatin green schists can only be ascertained by microscopical studies. The Thompson slates with the microscope are seen to be little altered fragmental rocks, while the green schists of the Mesabi range are thoroughly crystalline, and in many places altered volcanic rocks. Further, the crystalline schists of the Mississippi River are not connected by continuous exposure with the Thompson slates, and may belong to a different series from them. Certainly a much more thorough study of the problem is required before it can be considered as probable that Irving was wrong in placing the Thompson slates as a part of the Animikie series.

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